CHAPTER 4

PLUMBING INSTRUMENTS AND TILT MEASURING DEVICES

4-1. General.

a. Purpose. Plumb lines, inverted plumb lines, and optical plummets are designed to accurately measure bending, tilting,or deflection of concrete structures resulting from external loading to the structure, temperature changes within the structure, sliding of the structures, or deformation of the foundation. Through the measurement of structural deformations they will furnish information in regard to the general elastic behavior of the entire structure and foundation, provide a means for determining the elastic shape of the deflected structure which will permit separation of load deflection and thermal deflection components, and, with precise alignment data, provide for estimating the amount of translation or sliding.

b. Location. These instruments should be located in structures where unusual structural deflections are anticipated or where information on deflections is required. They should be located in the highest monoliths of the structure and at locations where reading stations will be easily accessible. The conventional type plumb bob system should be installed in structures where provisions for installing a plumb bob line near the top of the structure with a reading station in the lower part of the structure can be made. Reading points are provided in one or more of the galleries in the lower portion of the structure and at other elevations if practicable, where the position of the plumb line with respect to the structure is measured by a micrometer microscope. Plumb bob systems based on an inverted pendulum or deflectometer may be installed in structures where a reading station cannot be constructed near the base of the structure, or where it is desired to extend the reference points into the foundation.

4-2. Description.

a. Plumb Line. The conventional plumb line system is composed of a vertical shaft, a suspension assembly, a plumb bob, line, and dashpot, a reading station, and a microscope and micrometer.

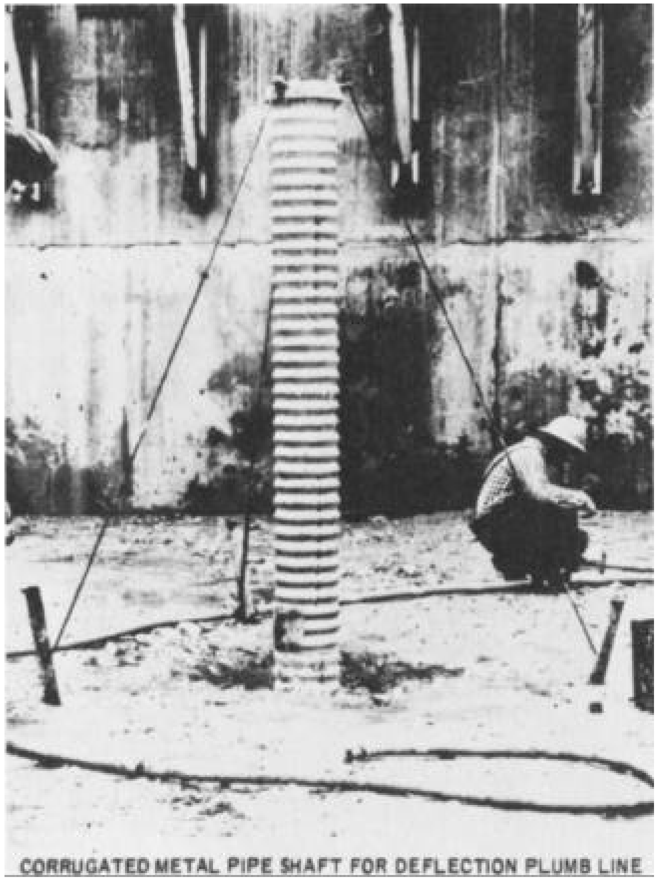
b. Shaft. The plumb line wire is housed in a vertical shaft, usually formed by embedding lengths of non-rusting rigid metal pipe in each concrete lift from the lowest reading station to the suspension point. Utilizing an elevator shaft or air vent for the plumb line shaft is usually unsatisfactory since the mechanical and air flow disturbances therein cause undesirable vibrations of the wire during observations.

c. Shaft Sizes. For deflection plumb lines of lengths up to 200 ft, an 8-in. diameter pipe installed with reasonable care will provide a clear projected opening of ample size to allow for maximum expected movements. A 12-in. diameter pipe is recommended for plumb lines exceeding 200 ft. Figure 4-1 shows a section of embedded pipe shaft in place, ready for placement of the next lift of concrete.

d. Suspension Assembly. The plumb wire is suspended at the upper end of the shaft by a suspension assembly as shown in Figure 4-1 and Plate 4-1. The suspension plate should be designed with a watertight cover to prevent moisture entry and corrosion of the wire.

e. Wire, Plumb Bob, and Dashpot. The wire suspending the plumb bob should be l/32-in. diameter stainless steel or other high-strength corrosion resistant steel wire. Satisfactory results have been obtained at Libby Dam by using a 20-gage stainless steel wire equivalent to Federal specification QQ W 390C. The plumb line will have a tendency to stretch with time so a suitable means of adjusting for stretch in the wire should be incorporated at the upper end of the plumb bob shaft. The major amount of stretch should occur within one month of installation.

f. Plumb Line Damping. The plumb bob shall be a conventional or job-built cylinder of a weight sufficient to maintain the wire steady and free from unwanted vibrations. Past experience has shown that at least 25 lb is necessary to weight the line. To damp the pendulum action of the wire and plumb bob and to minimize local vibrations of the wire an oil-filled container is provided in which the plumb bob is immersed. This dashpot must be at least 8 in. in diameter in order to insure free deflection of the plumb bob, and about 10 in. in depth. It should be filled with a noncorrosive oil and fitted with a deflecting metal cover if moisture traveling down the sides of the shaft or the plumb wire might contaminate the oil.



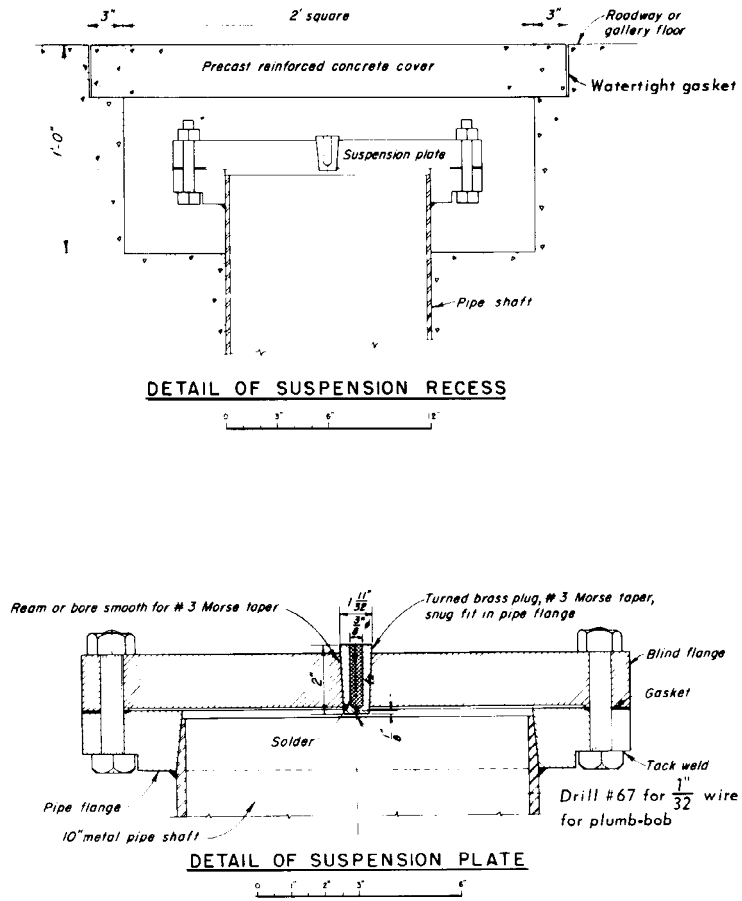


Figure 4-1 Corrugated metal pipe shaft at interface of a lift, and details of suspension plate attached on top of the shaft. (Prepared by CE-WES)

g. Reading Station Enclosure. The reading station should be located in the lower portion of the structure in the case of a conventional plumb bob system. It should be a recess in the concrete located in one of the galleries. The dimensions may be similar to those shown in Plate 4-1. The enclosure may also be used as a reading station for the inverted plumb line discussed later in this chapter. To prevent unauthorized access to the plumb line and reading station facilities, a sheet steel cabinet or doors should be provided at the recess. This also serves to eliminate undesirable plumb line movements sometimes caused by drafts. Illumination during readings is furnished by one or more adjustable spot lights, and a permanently lighted bulb or small strip heater will assist in reducing condensation and corrosion of the metal plates and bars within the recess. The cabinet doors should be provided with a suitable latch and lock.

h. Microscope and Micrometer. The movement of the structure is measured by the change in the distance between the plumb line and reference marks on the base plate attached to the structure. This is accomplished by measuring the distance between the plumb line and an etched line on the micrometer reference bar. The distance is read by a microscope mounted onto the reference bar at the reading station. Suitable instruments for this reading have been obtained from the Gaertner Scientific Corporation, 1201 Wrightwood Avenue, Chicago, Illinois 60614.

i. Reference and Microscope Support Bars. Within each reading station recess there are two 1/2-in. thick steel plates, welded together along one vertical edge at an angle of 90°. These plates are placed on edge, with the welded corner vertical, in a position such that the plumb line is located in the 90° quadrant formed by the plates. A pair of polished steel bars extend inward from and normal to each plate. One bar of each pair serves as a mount for the portable micrometer slide and microscope, while the second bar provides a surface upon which is inscribed a permanent reference point. A keyway is provided in the support bars to receive the keyed micrometer support clamp, and a flat face is ground along the reference bar. Machining and fabrication of the plates and bars must be carefully done in order to obtain true 90° angles. Originally the plate assembly was oriented at an angle of 45° with the structure axis, but this required adjustment computations to align the data to the movement of the structure. In recent years it has been more useful to orient the assembly with one plate parallel to the structure axis and the other perpendicular to it (in the case of arch dams, radially oriented) as seen in Plates 4-1 and 4-2.

4-3. Installation Procedures.

a. Recess. Forming the reading station recess to receive the microscope support rods and plates is a routine concrete construction procedure and is included with other form work.

b. Shaft. The plumb line shaft is made by installing lengths of metal pipe vertically from the top of the lowest recess up to the suspension point. Spiral welded steel pipe or corrugated metal pipe has been found satisfactory for this purpose. Special care in alignment and bracing is necessary to assure plumbness of the pipe sections and to insure a clear projected net opening approaching the full size of the pipe. Figure 4-1 shows one bracing arrangement which has been used.

c. Suspending the Plumb Bob. The plumb bob should be suspended from the center of the net opening of the plumb line shaft. This point must be located on the suspension plate so that the wire will hang from the suspension plate over the center of the shaft. It can be located by suspending a temporary plumb line from a transit located over the shaft. The plumb line should be sufficiently long to reach from the transit to the top of the reading station. A sheet of cardboard is secured in place directly beneath the lower end of the shaft, and a pattern of the clear projected net openings of the pipe established by marking the positions of the plumb bob as the suspension cord is moved around the periphery of the pipe at the top of the shaft. The plumb bob should be allowed to come to rest at each of the eight or ten points required to define the clear opening pattern. With the cardboard still in place the center of the pattern is established to within 1/4 in. and projected to the top of the shaft by means of the temporary plumb line. The permanent plumb line will be set as close to this center point as possible.

d. Permanent Installation. Installing the permanent plumb bob must be done with care to avoid kinks and twists in the plumb wire. The wire is threaded through the collet in the plug, through the suspension plate and attached to the plumb bob as shown in Figure 4-2. With a conventional plumb bob the cap may be removed and the connection made by threading the wire through the hole in the center of the cap, the interior of which contains a cone-shaped recess. The wire is twisted around a short nail lodged in the cone-shaped recess and hot solder poured in to cover the nail and fill the cup. After the solder has cooled, the cap is lowered through the shaft to the reading station as in Figure 4-3. When the plumb bob cap is at the level of the damping pot, the cap is screwed onto the bob, lowered into the damping pot and sufficient oil added to cover the plumb bob. The freely suspended bob is adjusted to an elevation just below the oil level in the dashpot, and the wire securely fixed at the suspension point.

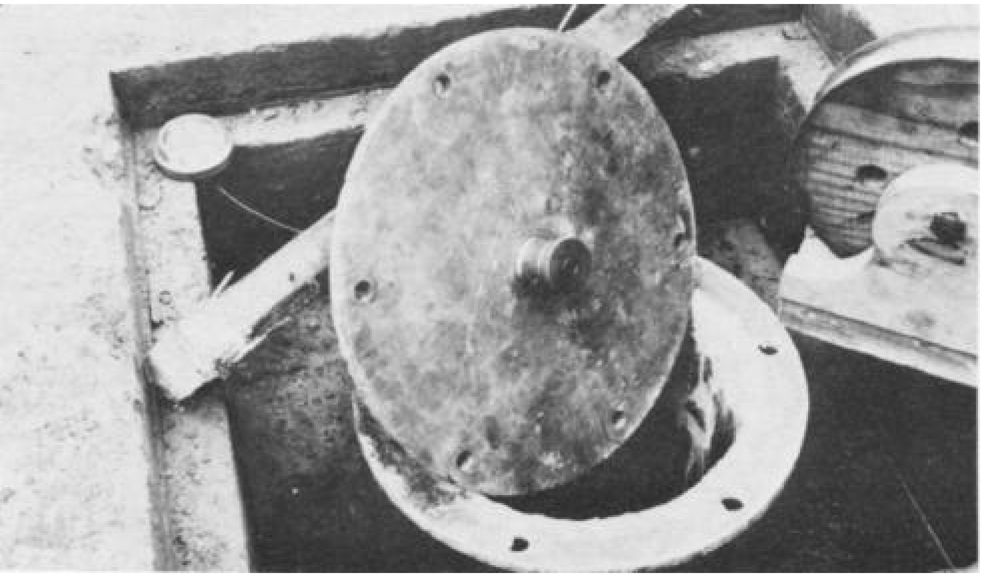


Figure 4-2. Attaching Wire to Plumb Bob Cap (Courtesy of the Tennessee Valley Authority).

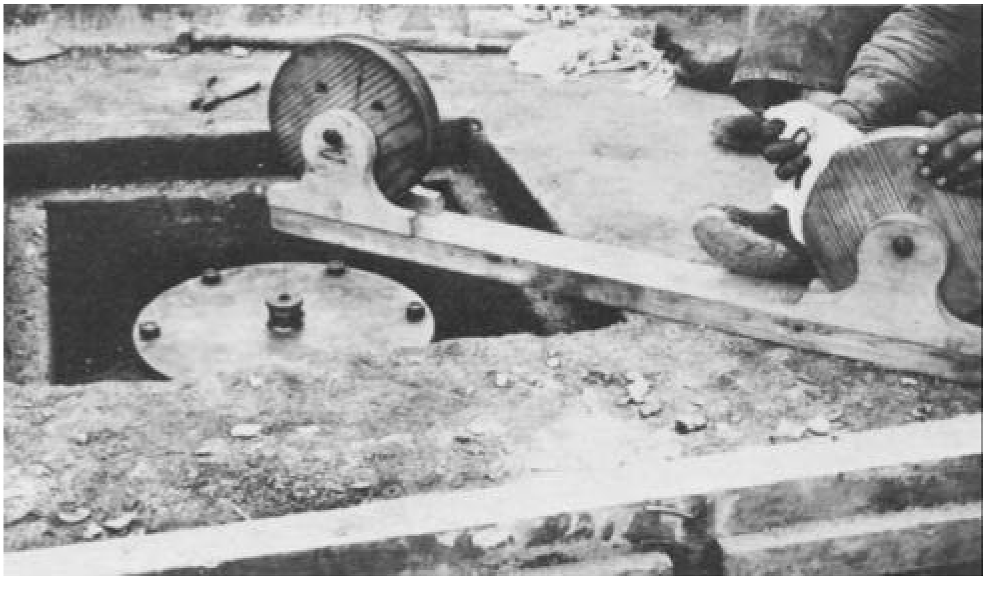


Figure 4-3. Lowering Plub Bob Cap and Wire Through Suspension Plate (Courtesy of the Tennessee Valley Authority).

e. Tightening the Plumb Wire. Since the wire is subject to stretching under the weight of the plumb bob, the attachment at the suspension plate should be made to be permanent but should have provisions for removing the slack as the wire stretches. Where the suspension point will continue to be reasonably accessible, the closing nut of the spring collet is tightened to securely grip and hold the plumb line wire. For suspension points which will become inaccessible, the spring collet may be eliminated, and the wire wrapped around a short nail, placed in a cone-shaped cup in the top of the suspension plate, and the cup filled with hot solder. In the situation where the suspension point will become inacessible provisions for removing the slack in the wire should be made at the plumb bob end. For protection of inacessible suspension points, two coats of red lead paint should provide the necessary protection.

f. Laying Out the Reading Station. The suggested layout of the reading station should be similar to that shown in Plate 4-1. Each station should consist of a recess in the concrete adjacent to a gallery or other accessible space containing access from above for the plumb line shaft, the reading apparatus and support assembly, adequate lighting to illuminate the reading apparatus, heating equipment to minimize moisture condensation and a dashpot filled with oil to dampen movement of the plumb bob.

(1) The position of the two microscope mounts and two reference bars attached to the bar support plates should depend upon the following:

(a) Maximum expected movement of the plumb line.

(b) Mechanical working distance of the microscope. This is the distance, in inches, from the front of the objective lens mount to the object plane.

(c) Length of telescope draw tube travel. This is the external range of the rack and pinion movement of the objective lens mount.

(d) Offset dimensions of the micrometer support clamp.

(2) The first step in determining this positioning is to establish the expected extreme positions of the plumb line shown in Plate No. 4-2. The range of annual movement in a direction normal to the axis of the dam is determined by adding the structural deflection due to a full reservoir water load to an estimated annual temperature deflection cycle. Both the annual temperature deflection cycle and the same cycle modified by the maximum load deflection are superposed upon the estimated permanent thermal deflection to obtain the maximum possible range normal to the axis of the dam. Since transverse movements are generally small and impossible to predict with any degree of accuracy, the transverse range of the plumb line is estimated to be at least one eighth of the total estimated upstream-downstream movement on each side of the initial position of the plumb line.

(3) The second step consists of determining the length and position of the reference bars and establishing the required size and characteristics of the microscope and micrometer slide. The shaded rectangle in plate No. 4-2 represents the area of extreme plumb line movement previously established, and the reference bars should be located as close as possible to the sides of this shaded area to increase reading accuracy. The optical characteristics of a selected microscope are laid off on the diagram to establish a position of the microscope from which the reference bar and plumb line may be viewed satisfactorily without interfering with plumb line movements. Modification of the mechanical working distance of the selected microscope is possible by substituting an objective lens with a different focal length. It is generally good practice to provide for at least 2 in. of clear distance between the end of the microscope and the plumb line movement rectangle, or more where the plumb line is exceptionally long or where foundation deformations may be considerable. The required range of the micrometer slide is determined by projecting the extremes of the movement rectangle upon the reference bar, and a micrometer slide selected which is capable of reaching each end of this projected dimension from the proposed location of the reference mark.

(4) The third step locates the position of the microscope support bar with respect to the reference bar. With the distance from the end of the microscope to the reference bar determined, the location of the micrometer slide which will receive the microscope is established. The dimensions of the clamp holding the vertical rod which supports the micrometer slide determines the position of the support bar with respect to the reference bar. The support bar is located at an elevation such that the microscope line of sight and the reference bar are in the same horizontal plane.

(5) After the bar sizes and locations have been worked out initially on the drawing board, and before fabricating the plates and bars, it is recommended that the dimensions and details be checked by a full-size mockup. The plates may be of wood, with holes drilled to receive the steel reference and support bars. Sightings with the microscope and micrometer slide should be made on a short length of plumb line suspended at extreme, as well as intermediate, positions to test the design layout.

g. Microscope and Micrometer Slide. The microscope and micrometer slide should be procured by the Government prior to installation of the plumb bob or fabrication of the bar support plates. Information on diameter of shaft, the mechanical working distance of the microscope and method of attachment of the micrometer slide to the reference bar will all be used to determine the size of the reference bars and position of reference and rider bars on the support plate. Gaertner Scientific Corporation, 1201 Wrightwood Avenue, Chicago, Illinois 60614, manufactures microscopes that insert in micrometer slides. Other manufacturers may also make acceptable microscopes and micrometers; this is just one source that has been used in the past with good results. When the plumb line movement is expected to be limited to a square having an area of 1-1/2-in. on a side, Gaertner model M101A microscope and micrometer slide with special modified mount model M301AD may be used. When a 4-in. square deflection area is considered necessary, it can be obtained by using Gaertner model M533 microscope, and micrometer slide modle M303A.

h. Alignment. The plumb bob and wire, suspension plate and bar support plate may be procured and installed by a contractor but coordination between the contractor and Government forces familiar with instrumentation is necessary, and final fabrication of the suspension plate and bar support plates should be withheld until information on actual installation of the shaft is completed. Setting the bar support plates, and machining and aligning the bars must be carefully done by a competent machinist, and the assembly checked repeatedly during erection by the engineer responsible for the instrumentation installation. Reliable deflection measurements demand the closest possible alignment between the parts and angular accuracy not exceeding 0.5 degree. The plates should be firmly secured in their proper position by backfilling behind the plates with concrete or by welding to anchor bolts in the floor or sides of the reading station recess.

i. Marking Reference Points. A permanent reference mark is scratched on the flat surface of each reference bar in the following manner; the vertical cross hairs of the microscope are aligned with the plumb line and the microscope then focused on the reference bar. With a straight edge or metal rule placed firmly against the reference bar and being plumbed by reference to the cross hairs, make a vertical scratch on the reference bar by one pass of a razor blade along the edge of the rule. A second, diagonal scratch is added, and the two scratches rubbed down to very thin lines with crocus cloth or fine abrasive powder. The point of intersection of the two lines is used as a base for referencing all subsequent positions of the plumb line.

j. Location of the Scribe Marks. By placing the reference scratches just upstream or downstream of, or towards the right or left abutment of, the plumb line travel area, all subsequent measurements of the plumb line will always be made to one side of the reference mark, and the error of identifying the direction of movement will be eliminated. The micrometer slide range should also be considered in locating the scribe mark so that it will not be exceeded by placing the mark so far downstream that the maximum measurement upstream may not be obtainable. If a micrometer with range smaller than the expected maximum plumb line travel is used, the reference marks should be scribed midway between the limits of expected plumb line movement. If this latter reference mark location is adopted, a thick stripe of colored enamel should be applied longitudinally along the flat face of the reference bar on one side of the reference point, and a contrasting colored strip on the other side of the point, to visually assist and remind the observer to recognize and record the position of the plumb line with respect to the reference mark. The scribe mark and initial readings should be performed by an instrumentation engineer familiar with the microscope and plumb bob system operation. The instrumentation engineer should train at least two of the project operating personnel in the use of the microscope and micrometer slide as these are precision instruments which require detailed instructions on their care and use.

4-4. Maintenance and Care of Equipment.

a. Reading Station Facilities. A light film of oil rubbed over the reference and support bars at the conclusion of each observation will afford supplementary protection against corrosion. This oil film, and any moisture condensation, should be wiped off when readings are made. Normally the only maintenance required for the plumb line will be keeping the oil-filled damping pot filled to the proper level, and checking to make sure that excessive stretching of the plumb wire has not occurred. Additionally, the light bulb or heating element in the reading station should be checked periodically to insure that it has not burned out.

b. Micrometer Slide and Microscope. The micrometer slide and microscope should be stored in their carrying case in a safe, -dry place, not in the reading station. Since they are precision instruments, they must be handled with care at all times. One or two drops of light lubricating oil applied to exposed screw threads and sliding surfaces of the micrometer at intervals of several months should be sufficient to keep the instruments lubricated.

4-5. Collection of Data.

a. Observation Technique. The microscope and micrometer slide are precision instruments designed for precise laboratory work, and should be used in a manner conforming to good laboratory practice. So far as practicable, all microscope readings should be made by the same individual, thoroughly familiar with procedures prescribed herein. Whenever it becomes necessary to change observers, either for a short period of time or permanently, the recommended step-by-step operations to be followed in making readings should be carefully explained and demonstrated to the new observer. A written instruction sheet usually will be found indispensible.

b. Recommended Procedure for Plumb Line Deflection Observations.

(1) Slide clamp, micrometer rod and collar, and micrometer onto the support bar, insert microscope, and clamp entire assembly in a position such that the reference mark and the plumb line fall within the range of the micrometer slide.

(2) Adjust position of micrometer rod and collar so that the microscope horizontal cross hair is slightly above or below the reference mark, and the plane of the micrometer slide movement is parallel to the reference and support bars. If the micrometer rod is properly keyed to the rod support clamp, this latter step is not necessary. Otherwise some other means must be used to assure that the microscope line of sight is exactly perpendicular to the reference bar. Sighting through the microscope into a small mirror held against the flat surface of the reference bar, and twisting the micrometer assembly until the cross hairs and their reflection coincide, may serve to determine the propert position.

(3) With the objective lens out of focus, focus the eye piece sharply on the system of cross hairs.

(4) For the next four steps, the positions of the micrometer rod and assembly support clamp must not be disturbed. Focus objective lens on the reference bar. By use of the micrometer slide wheel, move the slide and microscope well to the left of the reference mark, and then bring the slide back slowly until the reference mark is centered at the cross-hair intersection or between the parallel vertical hairs. stop the cross hairs precisely in the proper position; do not attempt to make slight adjustments by reversing the wheel motion. If the reference mark is "overshot", move slide to far left and start again. Read and record micrometer slide position.

(5) Repeat operation, approaching reference mark from the right, and record micrometer slide position. By approaching the reference mark both from the left and from the right, the effect of any slack in the gears and cogs of the slide mechanism will be eliminated.

(6) Focus objective lens on plumb wire. By means of the micrometer slide wheel, move the slide and microscope well to the left of the left edge of the plumb wire, and then bring the slide back slowly until the intersection of the cross hairs or the two vertical parallel hairs are centered on the left (or near) edge of the plumb wire. Do not adjust position by reversing wheel motion. Read and record micrometer slide position. Then continue movement of the slide until the cross-hair pattern is centered over the right (or far) edge of the plumb wire. Read and record micrometer slide position.

(7) Repeat operation, approaching plumb wire edges from the right side, and read and record micrometer slide positions.

(8) Visually observe and record the relative position (upstream or downstream) of the plumb wire with respect to the reference mark. The difference between the average of the Step 4 and Step 5 readings and the average of the Step 6 and Step 7 readings represents the dimensional position of the plumb line with respect to the reference mark.

(9) Repeat Steps 4 through 8 twice more from the same support bar.

(10) Repeat Steps 1 through 9 for the second pair of support and reference bars.

c. Reading Schedules. Initiation of the long-time observation program early in the life of the structure will provide data on the effects of cooling and temperature adjustments within the structure, early deformations of the foundation, and deflections of the structure under first applications of load. When a plumb bob system is being installed in an existing structure, the early pattern or readings will establish the movement of the structure such that at later dates less frequent measurement can be made.

d. Frequency of Readings. Daily readings should be made for about the first two weeks in order that the observer may become familiar with the equipment and procedures. A program of observations at weekly intervals should be followed for the first year, to define the range of cyclic movement and obtain detailed information on initial deflections. After this period a reading interval of about two weeks will adequately define the annual deflection cycle under normal reservoir operations. Observations at intervals of greater than a month are of little value. At least one reading should be made when the reservoir level approaches or reaches the maximum design pool elevation. Reading schedules should become more frequent in periods of extreme temperature or other conditions of nature where it is suspected that abnormal deflections may occur.

e. Special Observation Schedules. One or more special observation series may be required at selected installations to determine the amplitude of the daily movement cycle. Readings at intervals of two hours over a period of 24 or 48 hours, twice annually, are generally specified. Data obtained permits the determination of the magnitude of deflections due entirely to changes in surface temperatures of the structure, since external loads and annual temperature cycle adjustments will not vary significantly during the short observation period.

f. Supplementary Data. Reservoir pool and tailwater elevations (to the nearest foot) existing on the dates of observations must be included in the measured deflection records. A daily record of water surface elevations is more useful, and is usually available from routine project operation records or from other instrumentation data. Air temperature readings, from a recorder or from hourly observations, are required in connection with the special deflection observations series. Average monthly air temperatures for each month of long-time observation data are sufficient.

g. Coordination with Other Readings. The plumb line readings should be taken at the same time as the alignment readings are taken to allow an accurate pictures of the total movement of the structure.

4-6. Processing of Data.

a. Field Data Sheets. Micrometer slide readings for each of the three (or more if required) trials from each of the two microscope support bars at a reading station are recorded on a single field data sheet for each plumb line observation. This sheet is shown on Plate 4-3. Not only should the position of the plumb line (upstream or downstream or towards the left abutment or right abutment of the reference mark) be noted on the field sheet, but a scheme for identifying each of the two reference marker bars at a reading station must be adopted. This may be done by designating the reference bar on the right of the plumb line (nearest the right bank of the stream) as the A-bar, and the other the B-bar. Other schemes may be equally satisfactory, providing the meaning of the terminology is explained and is used consistently. Space is provided on the field sheet for noting weather conditions, dates, times, and similar data which frequently proves useful in interpreting unusual results. The field data sheets should be retained permanently, as they represent original and irreplaceable field notes.

b. Reduction of Data. The field data should be forwarded to the Engineering Division for computation and evaluation. The values of deflection can be directly read from column 13 of the Field Reading Sheet with the proper sign applied to this value. These values can be inserted into a deflection computation sheet similar to that shown in Plate 4-4 for a time history of deflection.

c. Presentation of Results. The deflection history plots (plate No. 4-4) should be prepared for the two principal directional movements at each reading station from the deflections computed on the data record sheets. The purpose of this initial plotting is to detect significant error in either the field observations or the data reduction operations, to eliminate minor discrepancies in the deflection movement cycle, and to provide deflection values at intermediate dates. The preparation of the history plots is the final step in the field data collection program.

4-7. Inverted Plumb Line.

a. General. The inverted plumb line is similar in construction and operation to the conventional plumb line. It consists of an anchor at the base or foundation, a plumb wire, and a float assembly at the top end of the plumb line. The float moves freely in a container of oil and establishes the plumbness of its wire from being perpendicular to the surface of the oil. It is used in conjunction with conventional plumb lines to extend the length of measurable plumb path and to make reading of a long path easier since both reading stations can be combined in the same opening.

b. Alternate Inverted Plumb Line. It is recommended that an inverted plumb line that is read directly beneath the float be used. It is also recommended that the inverted plumb line be located in the same monolith and reading station as the conventional plumb lines. However, if a situation arises where there are no convenient galleries, or it is desired to run the inverted plumb line from foundation to top of structure, an alternate type of inverted plumb line can be used. This system is shown in Plate 4-5, drawing 1, 2, and 3 of 3. The system is different in that the wire is not read as the moving element but a pair of cross hairs that are scribed on the top nut of the float and these cross hairs are read from above the float through a plexiglass cover. The cross hairs are read through a micrometer operated microscope mounted on the plexiglass cover. This system, shown in Figure 4-4, provides an alternate method of inverted plumb readings when galleries are not available. Since the wire is not the part of the system that is read, some errors due to twist of the float may be expected and the reading of the cross hairs can be hampered by condensation on the underside of the plexiglass.

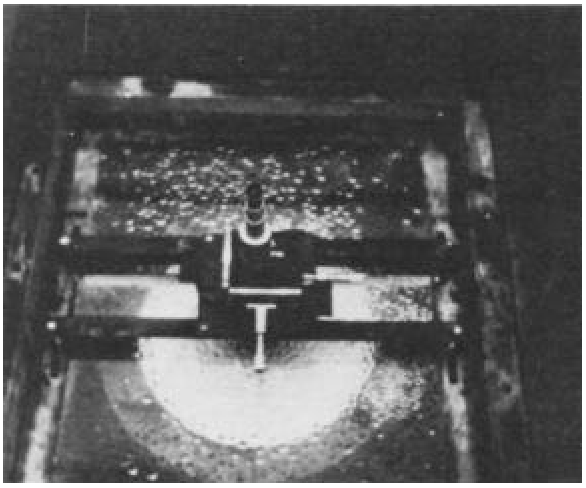


Figure 4-4. Float and Reading Assembly of Alternate Inverted Plumb Line. (Photo by WES)

c. Description of Components. The shaft and plumb wire requirements for the inverted plumb line are the same as for the conventional plumb line. The float assembly is the most changed from the conventional plumb line. It consists of a doughnut-shaped tank into which a doughnut-shaped float is placed and the container filled with oil. The float has the plumb wire attached to its center and the wire runs through the center of the doughnut-shaped tank as shown in Plate 4-5. The wire is weighted at the other end with a weight of approximately 25 lb similar to the conventional plumb line.

d. Installation.

(1) Anchor. The shaft can be drilled to the bottom of the monolith or can go into the foundation. The plumb wire is anchored to either a plate that is grouted into the bottom of the shaft or attached to a heavy weight that is cone-shaped on its bottom and sits in a cone-shaped receptacle grouted into the bottom of the shaft. The latter method is preferred since the weight can be retrieved if the wire should break and reinstallation is a simple procedure of repairing the attachment to the weight and lowering the weight back into its cone-shaped seat.

(2) Float Assembly. The tank and float should be installed directly above the reading station such that the length of wire that will be read for dam movement is close to the float. The tank should be supported on a frame that rests on the bottom surface of the readout station, and not secured to the concrete above the readout station. This prevents the possibility of the tank dislodging from the concrete and falling to the surface of the station. The oil should be put into the tank until the tension on the plumb wire is sufficient to keep the wire from vibrating.

(3) Readout Station. The inverted plumb line should be located in the same monolith with the conventional plumb line such that the same readout station that is used for the conventional plumb line can be used to read the inverted plumb line. The height of the readout station should be constructed so as to be comfortable for the personnel who will be reading the instruments. A reading light should be installed in the blockout such that it will provide proper illumination of the wire when it is to be read. A portable light constructed from the lantern from a miner's helmet and a moldable substance such as modeling clay can be made that will allow the operator to place his portable light exactly where he wants it. This light can be carried from station to station by the instrumentation party.

e. Data Collection. Data are collected in the same manner as is described in Paragraph 4-5. The reading schedule should also be as outlined in Paragraph 4-5.

4-8. Optical Plummet.

a. General. The optical plummet works on the principle of line-of-sight readings rather than the reading of the movement of a wire that is under the influence of gravity. Since they do not measure wire movement, they must rely upon bubble levels or mercury reflectors to keep the reading line precisely vertical. The more accurate plummets use the mercury reflectors making use of the reflection of the reading line-of-sight from the surface of a pool of mercury which is perpendicular to the vertical. Since these instruments operate on optical principles, they are susceptible to errors that are caused by refraction of light waves. Various errors can occur due to the atmospheric conditions between the plummet and the target, which become larger as the distance between the two increases. Also, changes in atmospheric density and temperature between the instrument and target cause refraction and distortion of the light waves which, in turn, cause small errors in the reading.

b. Accuracy. The optical plummets that have the highest accuracy are those which use a mercury horizon for reference to the plumb. These instruments have an accuracy of 1 in 300,000 or approximately 0.01 in. in 328 ft. One such instrument that has shown sufficient accuracy for high precision power dam surveys is the Wild GLQ Precision Nadir Plummet with mercury horizon, shown in Figure 4-5. It is available from Wild Heerbrugg Ltd., CH9435 Heerbrugg, Switzerland, on a special order basis. It is recommended that if it is desirable to use an optical plummet for vertical plumbing, that the less accurate plummets that rely on bubble levels not be used since a more precise method is available through the use of the inverted or conventional plumb line.

c. Description.

(1) Instrument. The instrument consists of a telescope mounted on a rotating base that is graduated in degrees. The location of the telescope on the rotating base is controlled by a micrometer such that the position of the cross hairs in the telescope eyepiece is always described by a rotation and a translation. The-entire instrument sits on a ring that has three self-centering holes arranged in a triangle with unequal legs such that the instrument will always be mounted in the same manner for each reading.

(2) Targets. The targets on which the instruments are sighted are of the fixed variety. They should have graduated blocks of a known width, such as 1 or 2 cm painted on the surface for obtaining the movement of the structure. The smaller the blocks, the greater the plumbing accuracy.

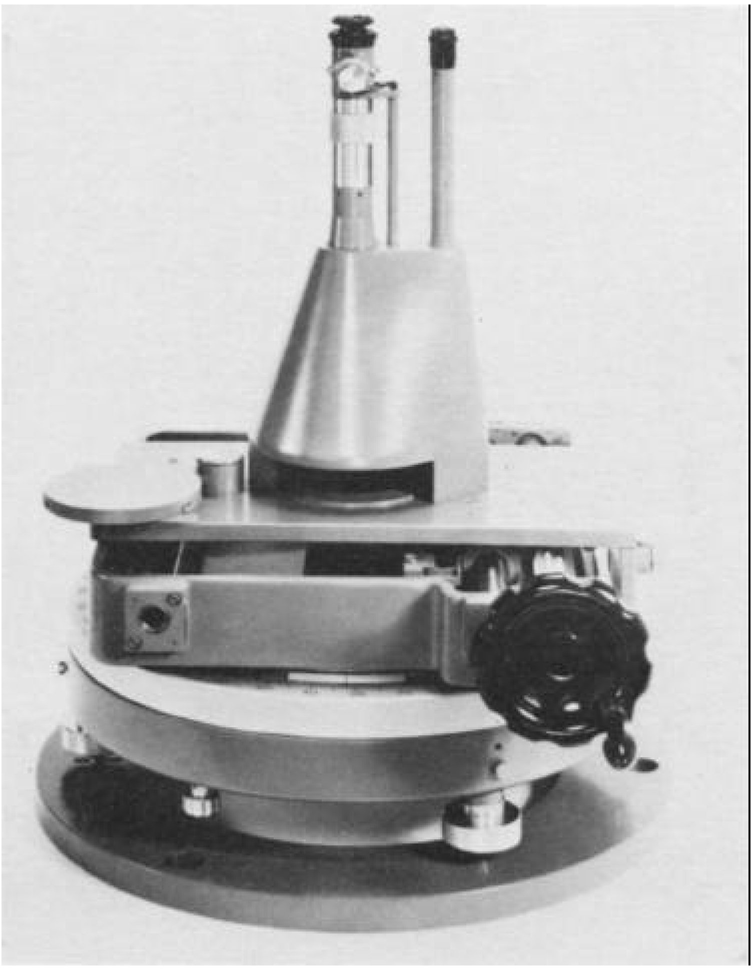


Figure 4-5. Wild GLQ Precision Nadir Plummet (Courtesy of Wild Heerbrugg Ltd.).

(3) Shaft. The shaft that holds the targets can be any convenient diameter, but it should be large enough to allow easy reading of the targets along its length. The targets should be spaced along the length of the shaft from top to bottom in order to get both relative movement and overall monolith movement (with respect to the base or foundation) and they should be well lighted for easy readability. If the air in the shaft should become heated, then the heat will affect the optical sight line and produce distorted readings; for this reason, the light sources used to illuminate the targets should be cool, fluorescent-type bulbs that do not distort the light waves.

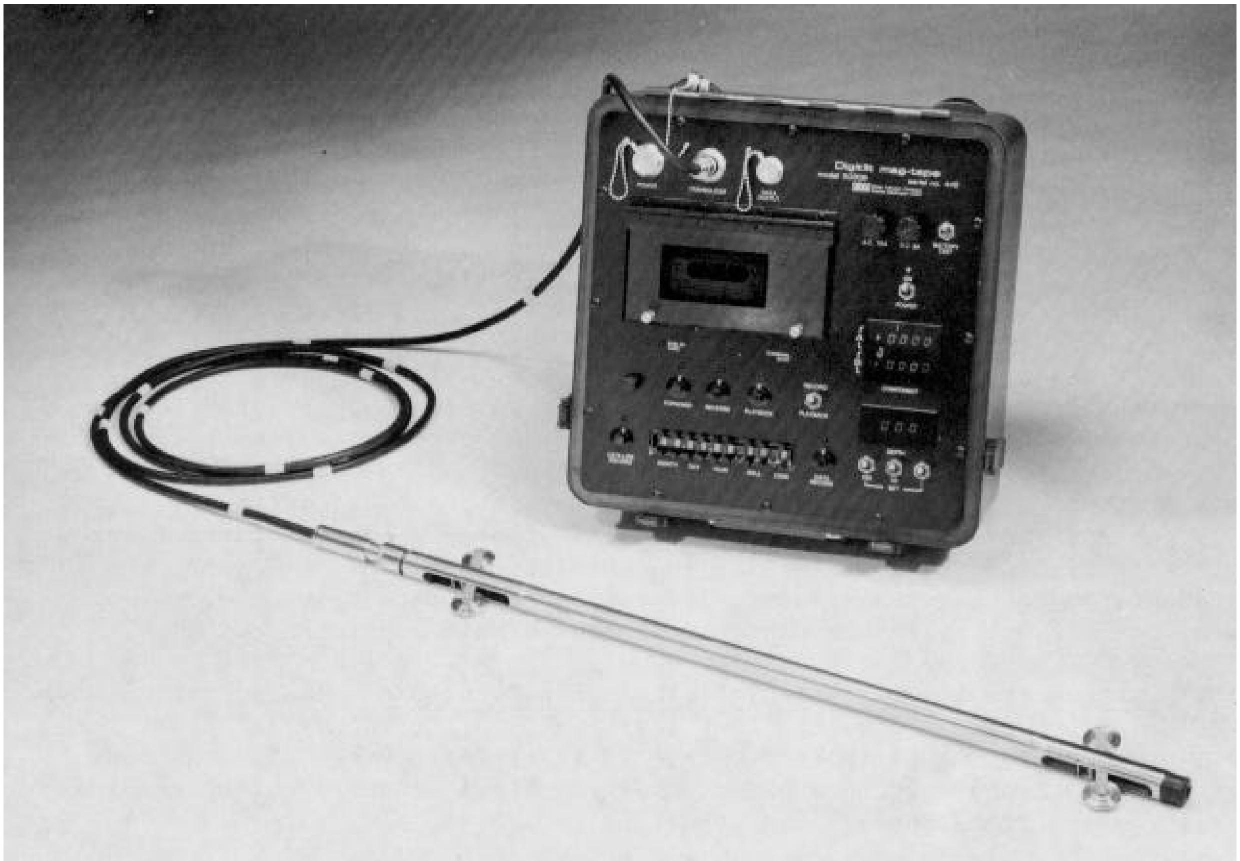
* 4-9. Tilt Measuring Instruments. The tilting or deflection of concrete structures resulting from external loads, temperature changes, or deformation of the foundation is a vital piece of information for evaluating structural safety and stability. This section provides information on types of instruments that are available, both commercially and by special construction, that are capable of measuring tilt in concrete structures. Some of these instruments were designed to measure tilt and some were designed for other uses but are adaptable to tilt measurement. Some measure surface tilt only, while others can measure tilt at various elevations within a structure.

4-10. Instruments that Measure Tilt Through a Structure. These instruments, most generally, are devices that are lowered through some sort of pipe, borehole, or channel that has been constructed in the structure. The instrument is not fixed to the structure but moves through this channel taking readings at desired locations through the structure.

a. Digitilt Inclinometer. This instrument, manufactured by Slope Indicator Co. of Seattle, Washington, is mainly designed for measuring lateral movements in earth embankments and rock foundations. However, it can be installed in concrete structures to make tilt measurements.

(1) Description. The sensor is shown in Figure 4-6 along with its digital read-out indicator. The sensor is 36.5 inches in length and has an outside diameter of 1.69 inches at the body. Two pairs of spring-loaded wheels at the top and bottom of the sensor guide the sensor when inserted into the casing which is either an aluminum or plastic tube having four lengthwise grooves spaced 90 degrees apart on its inside circumference. These grooves guide the sensor in two orthogonal directions of measurement. The electrical cable connected to the sensor is 0.42 inches in diameter, six-conductor cable with a 1/16-inch stranded steel center wire to support any tension on the wires. A water-proof neoprene cover surrounds the wires and the cable has external markings at each l-foot increment. This inclinometer has the overall sensitivity of one part in 10,000 or to .OOOl-foot lateral movement per 2 feet of casing.

(2) Installation Procedures. The only portion of the instrument that is permanently installed in the concrete structure is the inclinometer casing. This portion of the instrument is fitted into a borehole and then backfilled with a suitable supporting material (generally a cementitious grout). The borehole should be approximately 8 inches in diameter. This will,



* Figure 4-6. Digitilt Inclinometer and Digital Readout Indicator

accommodate all sizes of inclinometer casings. The borehole is drilled to below the elevation where measurement is required. Both the aluminum and plastic casings are installed in either 5- or 10-foot sections. The sections are butted together and joined by means of a sleeve that is pop riveted to the sections on each side of the joint. Care should be taken in the joining process to minimize any possible spiral of the grooves in the casing. As each successive section of casing is added to the previous length, the grooves must be aligned with the grooves in the previous section. Care should also be taken to install and backfill the inclinometer casing so that it remains vertical. This is not critical with respect to reading the instrument since the first set of readings produces a baseline condition, and all subsequent readings are relative to the baseline; however, the less vertical the casing is, the smaller the reading range becomes.

(3) Method of Operation. The sensor consists of two servo-accelerometers, one with its sensing axis in the same plane as the spring-loaded wheels and the other at 90 degrees to the first. Changes in tilt with respect to the vertical move a servo-accelerometer. This circuitry produces a restoring current, the magnitude of which is a measure of the tilt. The voltage output from the circuit is proportional to the sine of the angle made *

*between the longitudinal axis of the sensor and the vertical. Sensor elements housing the 0.5-gram accelerometers have a range of operation through ±30 degrees from the vertical, while l.0-gram accelerometers can function through ±90 degrees from vertical. The voltage output from the sensors is sent to a digital read-out indicator where the output is displayed on an illuminated digital display. A more sophisticated method of read-out is provided by means of a magnetic tape indicator (Figure 4-6) that will record the sensor voltage output directly on tape as well as display the voltage digitally.

(4) Data Collection. Output data are read with a four-digit bipolar digital voltmeter. It is self-contained and runs on a 6-volt rechargeable battery which allows operation for a period of 8 hours before requiring recharging. The output is given as a voltage that represents a variation from the vertical through the equation:

$$\Theta = \sin^{-1}(V/2)$$

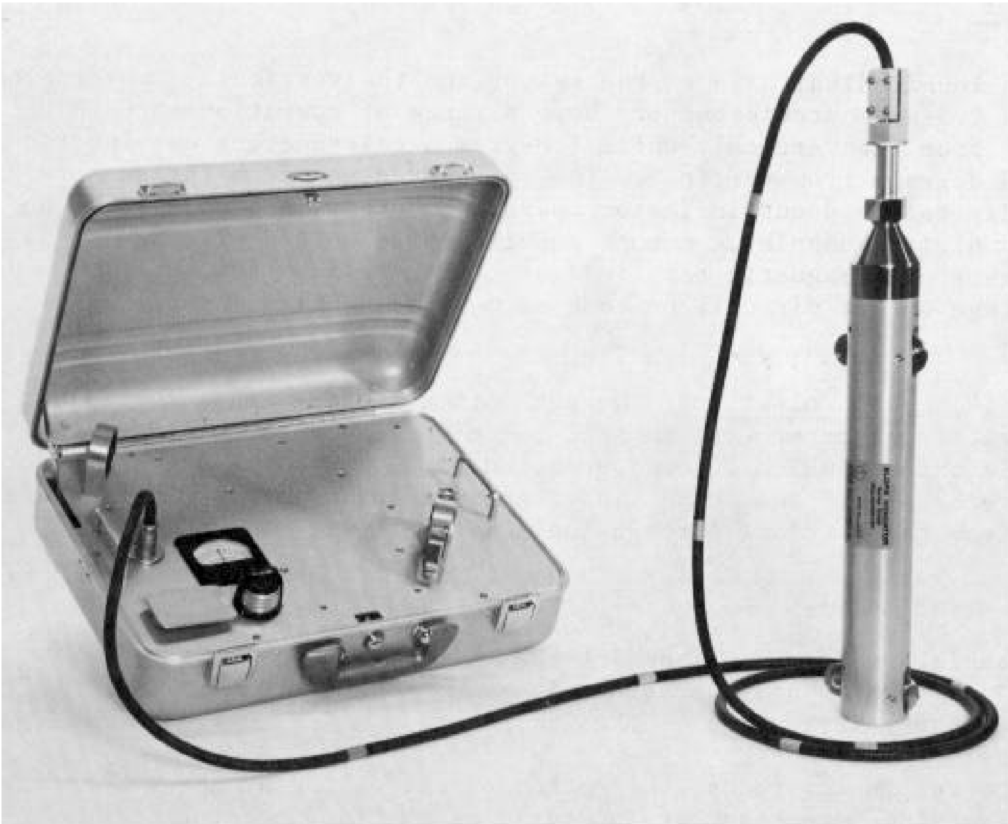
where Θ = angle, in degrees, made between the longitudinal axis of inclinometer and the vertical.
V = output voltage read on the indicator.

The inclinometer is lowered to the bottom of the casing by the connecting cable, and readings are taken at intervals as the inclinometer is raised from the bottom of the casing. The voltage reading is transferred to field data sheets for later computations. An alternative read-out device is available that eliminates the possibility of errors obtained by misreading or miscopying the manual read-out. The device is a magnetic tape recorder that automatically records the output on tape. This tape can then be read into a computer for automatic processing of the raw data.

(5) Care and Maintenance. The inclinometer and its indicator are not part of the permanent installation and, as such, are not subjected to continuous field weather conditions. They should be given the same care that any sensitive field instrument is given. The indicator casing remains in the field at all times. By virtue of its construction, either plastic or aluminum, it is generally maintenance free; however, the casing should be protected by a cap that is designed to prevent debris and water from entering when the casing is not being used.

b. Slope Indicator. This instrument is similar to the Digitilt inclinometer but is less sensitive to tilt due to its method of operation. It is a less expensive instrument manufactured by the same company, but can be used to make tilt measurements.

(1) Description. The slope indicator is shown in Figure 4-7. It is 2.38 inches in diameter and 15 inches in length. It is connected to read-out instrumentation by a cable similar to the Digitilt inclinometer. It is guided through its casing by a set of spring-loaded wheels also similar to the Digitilt inclinometer. *



* **Figure 4-7.** Slope Indicator Series 200B Inclinometer With Reading Instrument

(2) Installation Procedures. The instrument casing is the only portion of the instrument that is installed, and its installation is the same as that described for the Digitilt inclinometer.

(3) Method of Operation. The Slope Indicator instrument consists of a pendulum-actuated conventional Wheatstone Bridge circuit within the sensor. The pendulum contacts a fixed resistance element which subdivides the element into two resistances forming one-half of the Wheatstone Bridge. The other half of the bridge is contained in the control case in the form of a l0-turn precision potentiometer which is manually operated to balance the bridge. The lo-turn potentiometer is coupled to a counting dial reading from 0 to 1000. The inclination of the instrument is proportional to the potentiometer dial reading when the circuit is in balance. The instrument has a sensing range of ±12 degrees from the vertical. It has a sensitivity of 1 part in 1000, which means it cannot measure tilt of less than 3 minutes of arc.

(4) Data Collection. Data are taken by balancing the Wheatstone Bridge. A potentiometer in the bridge is coupled to a counting device registering from 0 to 1000. The number read from the counter when the bridge is balanced is proportional to the angle of tilt of the instrument. Raw data of counter readings are taken in the field and later reduced to angle of tilt. *

* (5) Casing Spiral. As mentioned earlier, spiral of the grooves in the inclinometer casing will *cause* errors in instrument readings. Consequently, inclinometer installation extending to a depth greater than 50 feet should be checked using the spiral meter developed by MRD Laboratory* or other proven devices to measure the angular change of grooves in the casing for the purpose of correcting the displacement direction as measured by tiltmeter data.

c. Wall Deflection Pipes. Several instruments that fall under the category of instruments that measure tilt through a structure must be installed in the structure during its construction. These instruments rely on a shaft or casing that has been cast into the structure in order to make their measurements. Two instruments requiring shafts are the plumb line and the optical plummet referred to earlier in this chapter. The instrument that requires a cast-in-place casing is the wall deflection pipe.

(1) Description of the Instrument. The wall deflection pipes and deflectometer (Figure 4-8) are designed and constructed at the U.S. Army Engi*neer* Waterways Experiment Station (WES). The equipment consists of a deflectometer, which is a compound vice and two dial deflection gages, a plumb bob attached to the deflectometer, and a casing which is made up of flanged sections of 5 inches inside diameter iron pipe. The casing extends from the top of the structure down to a point below where the lowest reading is to be taken. At each joint between pipe sections, there are mounted four silver-plated brass contact rods oriented around the inside wall of the pipe with each rod at 90 degrees to the adjacent rod. They serve as contact points inside the pipe.

(2) Installation Procedures. Proper alignment and plumbness of the deflection pipe are important in the installation procedure. The pipe base plate installation is most important with respect to alignment. It is installed in the monolith at an elevation approximately 5 feet below the elevation of the first instrument reading point. Three anchor bolts are cast into the top of the previous concrete lift such that they will be properly aligned with the three slotted holes in the base plate shown in Figure 4-9. The base plate is leveled by adjusting nuts on either side of the plate flange and serves to hold its alignment. It is important to align the scribe cross hairs on the base plate parallel to the two orthogonal directions in which measurements will later be taken. If the base plate is not properly aligned, none of the pipe sections will be properly aligned since they all key on the base plate. When the base plate has been properly aligned and leveled, the nuts on the anchor bolt are tightened. The leveling and alignment should be checked after tightening the nuts and the first pipe section then placed on

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* The equipment and an operator can be made available to Divisions and Districts upon request. Inquiries should be directed *to* the Director, MRD Laboratory, 420 South 19th Street, Omaha, Nebraska 68102, phone (402) 221-3207, FTS 864-3207. *

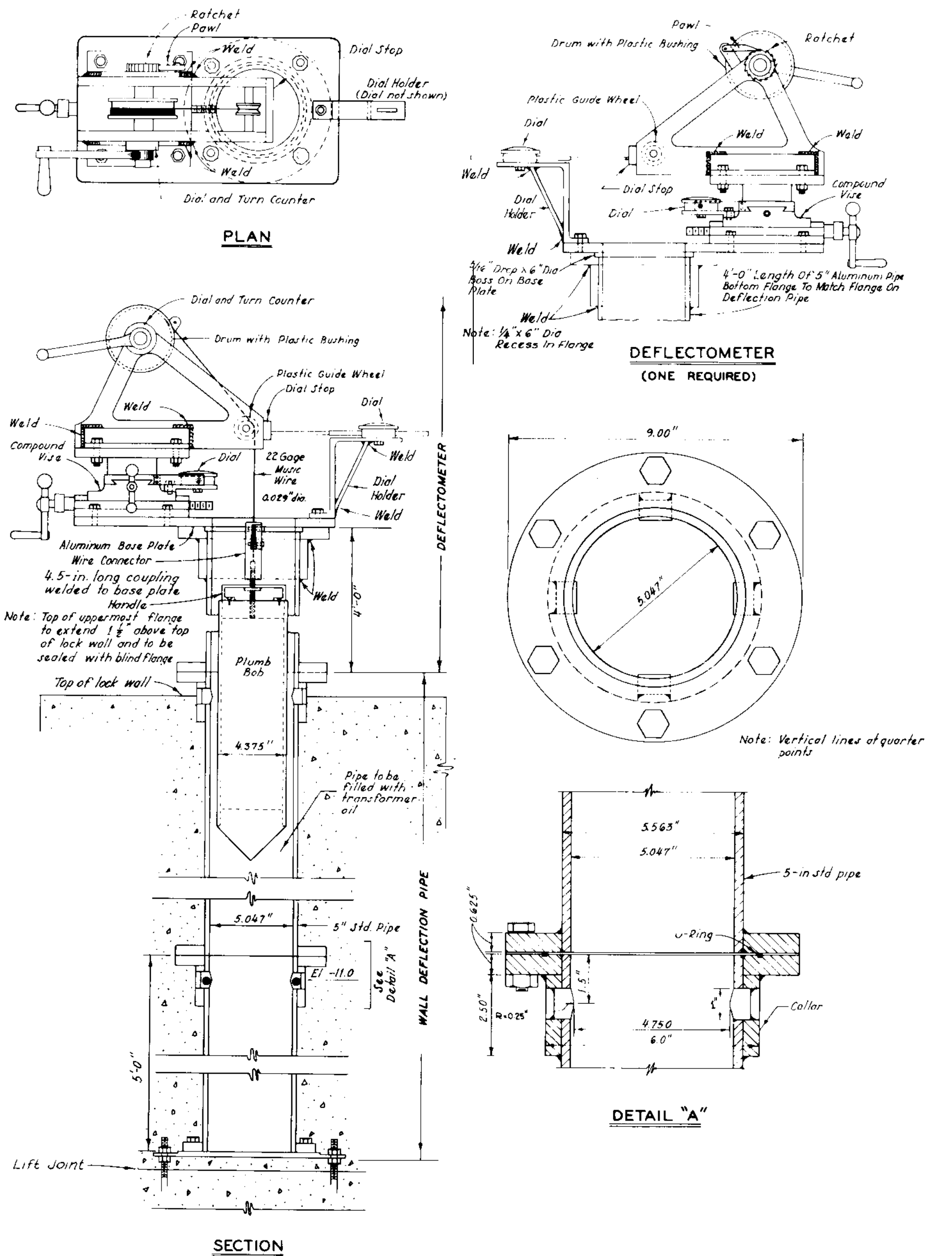
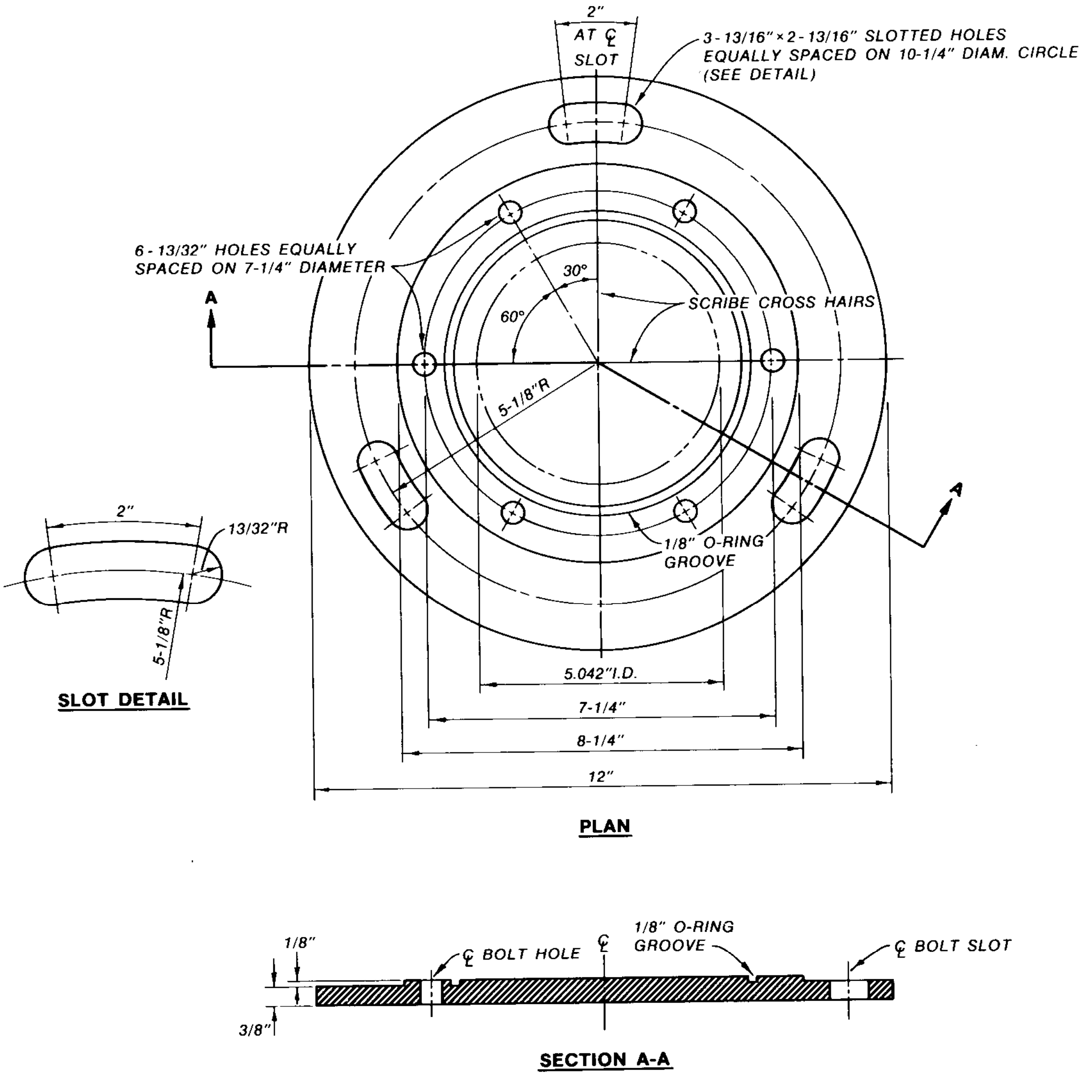


Figure 4-8. Details of Wall Deflection Pipes and Deflectometer



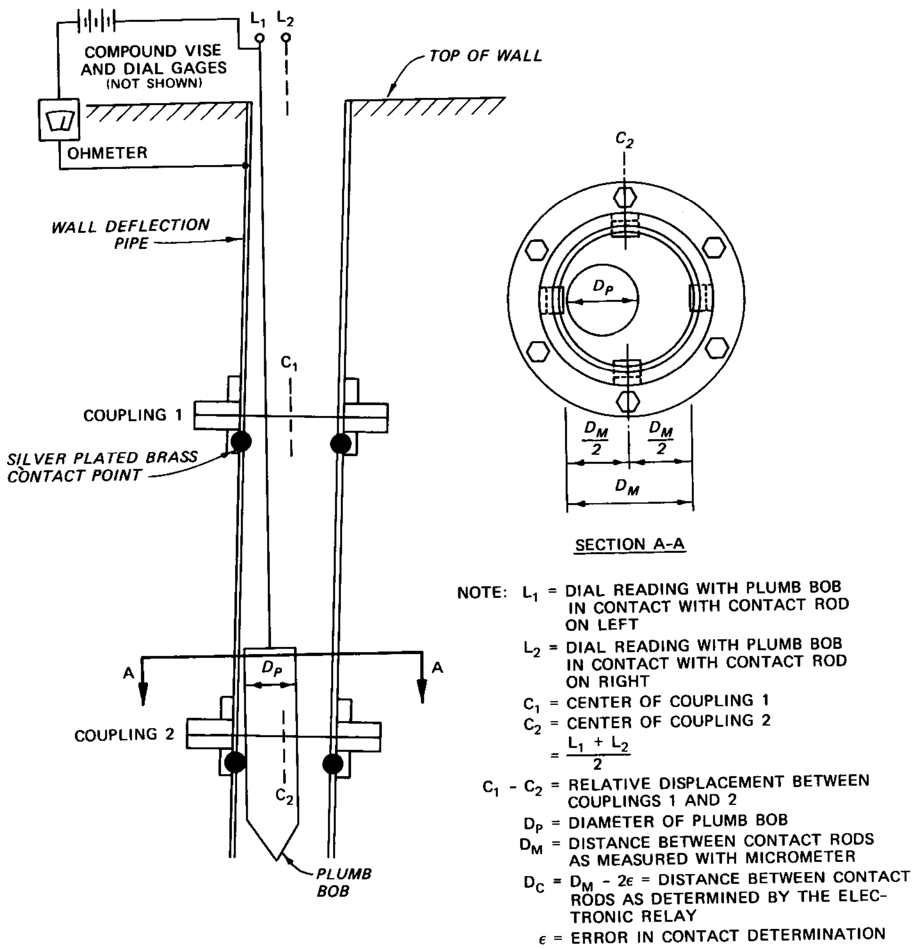
* Figure 4-9. Base Plate of the Wall Deflection Pipe

the base plate. Plumbness of each pipe section is achieved by leveling. A proper sized "0" ring must be placed in the groove provided in the base plate before the first pipe section is installed. After the first section of pipe is secured to the base plate with six machine bolts, it is stabilized by attaching three anchor rods to the top pipe flange and secured to the concrete lift below. Turn buckles should be installed in the rods just below the pipe flange. This is done by inserting eye bolts through three bolt holes in the flange and attaching the turn buckle to the eye bolts. A special temporary cover plate, machined to make its faces precisely parallel, is placed over the top of the pipe. The top surface of the temporary cover plate is then made level by adjusting the turn buckles. This, in turn, plumbs the pipe. When the deflection pipe section has been plumbed, the concreting operation can begin. As the concrete lift is being placed, the level of the temporary plate should be checked and adjusted as the lift rises until it is no longer possible to manipulate the turn buckles due to the elevation of the fresh concrete. *

* At this point the eye bolts should be removed from the flange. The top flange of the deflection pipe should emerge approximately 6 inches from the top of the completed lift. The temporary cover plate should be replaced with a less expensive plate and be left on the top flange until the next pipe section is installed. This will prevent water and debris from entering the pipe. Each remaining section of pipe is installed in the same manner as that of the first. The top of the last pipe section should extend no less than 2-5/16 inches above the top of the structure in order to mate with the deflectometer that fits on top of the deflection pipe. After the deflection pipe has been installed, it should be filled with transformer oil which will act as a damping medium to the swing of the plumb bob in the pipe. Care should be taken in filling the pipe with oil to prevent air entrapment.

(3) Method of Operation. Figure 4-10 is a schematic diagram showing the equipment operation. The plumb bob is lowered into the pipe to contact elevations and moved in four directions 90 degrees from each other until contact is made as determined electronically. Horizontal positions of each set of contacts in respect to each other are determined from deflection gage readings taken upon contact and, therefore, the positions of each set in respect to the bottom set of contacts. For each coupling the positions of two contact points are determined so that the center of each coupling is established. In this manner any inherent errors in determining the points of contact are partially compensable. Changes in the relative position of the coupling centers based on subsequent measurements indicate the lateral movement which occurs during the period between the two observations. The apparatus was designed to measure changes in alignment of the wall from the vertical of ±2 inches with an accuracy of ±0.0l inches over a height of 68 feet. Details of the instrument and its method of operation can be obtained through the Instrumentation Services Division of the WES.

(4) Data Collection. The deflection pipe is read by moving the plumb bob within the deflection pipe until an electrical circuit is completed. The plumb bob is moved towards or away from the contact bar by means of the deflectometer shown in Figure 4-8. The circuit, which consists of a battery, an ohmmeter, and the plumb bob, is an open circuit whenever the plumb bob is not touching a contact bar. It becomes a closed circuit when the bob touches a bar. The reading technique consists of moving the deflectometer so that the plumb bob approaches a contact bar. The proximity of the plumb bob to the contact bar may be monitored by observing the ohmmeter. As the plumb bob comes in close proximity to the contact bar, the infinite reading on the ohmmeter will begin to drop. At this point, movement of the deflectometer should be slowed and the ohmmeter monitored until the resistance drops to, or close to, zero. When the resistance measures zero, contact has been made and the dial gage attached to the deflectometer can be read. The same procedure is followed to read the contact bar on the opposite side of the pipe. With these two readings an average can be computed that describes the location of the center of the pipe. Figure 4-11 shows a sample deflection pipe data sheet with computations for 11 sets of readings through a monolith. The sheet contains each dial gage reading (E, W or N, S), the computation that describes the center of the deflection pipe, (E + W)/2., and a check calculation that *



* **Figure 4-10. Schematic Diagram of Equipment Used for Measuring Wall Deflections**

should equal the distance between opposing contact bars, $|E - W| + P.B.$ This check reading insures that the dial readings were recorded properly. For instance, in Figure 4-11, the check computation made for the dial readings of coupling No. 7 made on 8 July shows an error. The check calculation should be 4.750 ± 0.001. A check of the dial reading data shows that the 2.894 reading is suspect and should be corrected to 2.794. Figure 4-12 shows the computation sheet for the data in Figure 4-11. The deflection computation is made by computing the difference between the center of the pipe at the elevation in question, and the center of the pipe at the lowest measurable elevation.*

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* This procedure assumes that the lowest point in the pipe does not move, which makes the deflection of all the points above the lowest one relative to the movement of the lowest point. *

WALL DEFLECTION PIPE DATA SHEET

Project SAMPLE DATA SHEET Deflection Pipe No. S1

Plumb Bob Dia. 4.299 Observed by ______ Date 5 Jan & 8 Jul

Coupling No.	Counter Reading	Dial Reading E	Dial Reading W	$\frac{E+W}{2}$	$\lvert E-W \rvert$ +P.B.	Dial Reading N	Dial Reading S	$\frac{N+S}{2}$	$\lvert N-S \rvert$ +P.B.
DATE 5 Jan									
1 El. 30.0		3.482	3.032	3.257	4.749	3.366	2.914	3.140	4.751
2 35.0		3.472	3.022	3.247	4.749	3.392	2.940	3.166	4.751
3 40.0		3.457	3.007	3.232	4.749	3.389	2.937	3.163	4.751
4 45.0		3.420	2.969	3.194	4.750	3.357	2.906	3.132	4.750
5 50.0		3.372	2.922	3.147	4.749	3.345	2.893	3.119	4.751
6 55.0		3.294	2.844	3.069	4.749	3.330	2.879	3.104	4.750
7 60.0		3.218	2.767	2.992	4.750	3.304	2.852	3.078	4.751
8 65.0		3.120	2.670	2.895	4.749	3.281	2.829	3.055	4.751
9 70.0		2.983	2.533	2.758	4.749	3.241	2.789	3.015	4.751
10 75.0		2.857	2.407	2.632	4.749	3.191	2.739	2.965	4.751
11 80.0		2.672	2.222	2.447	4.749	3.116	2.664	2.890	4.751
DATE 8 Jul									
1 El. 30.0		3.183	2.733	2.958	4.749	3.850	3.399	3.625	4.750
2 35.0		3.143	2.693	2.918	4.749	3.896	3.444	3.670	4.751
3 40.0		3.115	2.665	2.890	4.749	3.901	3.449	3.675	4.751
4 45.0		3.056	2.606	2.831	4.749	3.870	3.419	3.645	4.750
5 50.0		2.988	2.537	2.763	4.750	3.834	3.383	3.609	4.750
6 55.0		2.896	2.446	2.671	4.749	3.800	3.348	3.574	4.751
7 60.0		~~2.894~~ 2.794	2.342	~~2.618~~ 2.568	~~4.851~~ 4.751	3.749	3.298	3.524	4.750
8 65.0		2.659	2.208	2.434	4.750	3.714	3.263	3.489	4.750
9 70.0		2.509	2.059	2.284	4.749	3.658	3.207	3.432	4.750
10 75.0		2.358	1.908	2.133	4.749	3.601	3.149	3.375	4.751
11 80.0		2.173	1.723	1.948	4.749	3.536	3.084	3.310	4.751

WES Form No. 1084
May 1960

* Figure 4-11. Data Sheet for Deflection Pipe Readings *

DEFLECTION PIPE COMPUTATION SHEET

PROJECT Sample Computation Sheet

DEFLECTION PIPE NO. S1 OBSERVED BY ______________ DATE 5 Jan & 8 Jul

Date	East-West Direction			North-South Direction	
	Contact Elev	Center Reading	Deflection	Center Reading	Deflection
5 Jan	30.0	3.257	0	2.914	0
	35.0	3.247	W 0.010	2.940	S 0.026 (+)
	40.0	3.232	W 0.025	2.937	S 0.023 (+)
	45.0	3.194	W 0.063	2.906	N 0.008 (-)
	50.0	3.147	W 0.110	2.893	N 0.021 (-)
	55.0	3.069	W 0.188	2.879	N 0.035 (-)
	60.0	2.992	W 0.265	2.852	N 0.062 (-)
	65.0	2.895	W 0.362	2.829	N 0.085 (-)
	70.0	2.758	W 0.499	2.789	N 0.125 (-)
	75.0	2.632	W 0.625	2.739	N 0.175 (-)
	80.0	2.447	W 0.810	2.664	N 0.250 (-)

Date	East-West Direction			North-South Direction	
	Contact Elev	Center Reading	Deflection	Center Reading	Deflection
8 Jul	30.0	2.958	0	3.625	0
	35.0	2.918	W 0.040	3.670	S 0.045 (+)
	40.0	2.890	W 0.068	3.675	S 0.050 (+)
	45.0	2.831	W 0.127	3.645	S 0.020 (+)
	50.0	2.763	W 0.195	3.609	N 0.016 (-)
	55.0	2.671	W 0.287	3.574	N 0.051 (-)
	60.0	2.568 ~~2.618~~	~~W 0.340~~ W 0.390	3.524	N 0.101 (-)
	65.0	2.434	W 0.524	3.489	N 0.136 (-)
	70.0	2.284	W 0.674	3.432	N 0.193 (-)
	75.0	2.133	W 0.825	3.375	N 0.250 (-)
	80.0	1.948	W 1.01	3.310	N 0.315 (-)

Figure 4-12. Computation Sheet for Deflection Pipe

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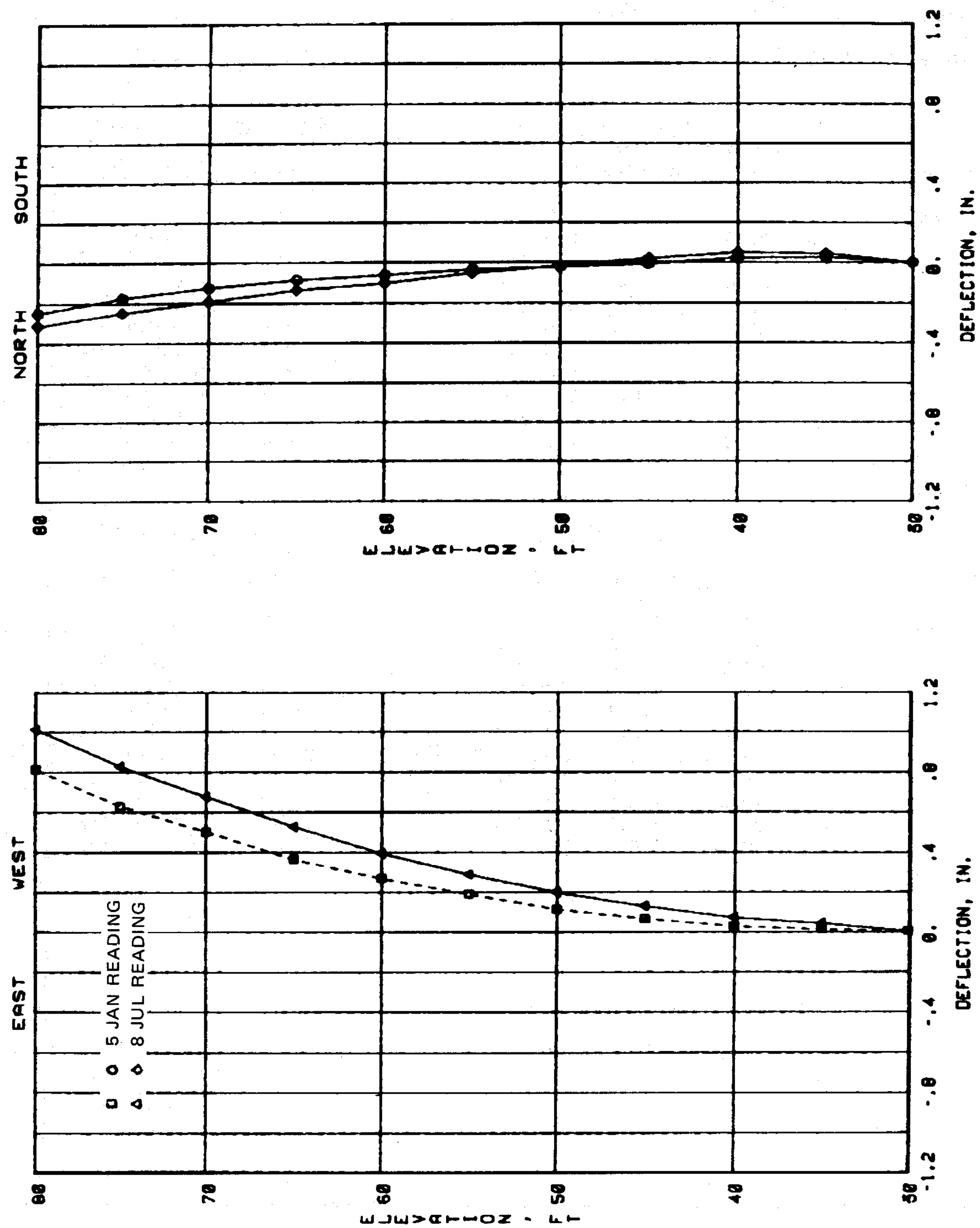

Figure 4-13. Typical Graph of Deflection Versus Elevation

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*The data are typically reported as a graph of elevation versus deflection as shown in Figure 4-13, which is a graph of the computed data from Figure 4-12.

4-11. Instruments that Measure Surface Tilt. This category of tiltmeter includes the instruments that are located at one site, and provide a record of tilt for a given location. They may be fixed, in which case a number of these instruments may be necessary to describe the tilt of a structure, or they may be moveable in which case one unit is moved around and used to measure the tilt at a number of locations. In general, the former can be automated, and the latter must be accomplished by manual means. *

a. Electrolevel.

(1) The "Electrolevel", shown in Figure 4-14, is a British instrument which is designed to provide a remote-reading facility for measurement and control of small angular movements. It has a spirit level vial with a precision-ground upper surface that is filled with an electrically conducting liquid and has three electrodes of platinum rigidly attached to the inner surface. The liquid is an alcoholic solution that has virtually the same properties as the liquid of a spirit level. The bubble runs on the curved surface which is free from discontinuities over the operating range. Movement of the bubble changes the electrical resistance values between the inner and outer electrodes. By using an alternating current bridge circuit the bubble position can be read with a pointer-type instrument (meter movement).

(2) The Electrolevel vial provides an electrical signal proportioned to the angular deviation from horizontal over a range of ±30 minutes of arc. When used with a bridge circuit and detector amplifier, indications of tilt of less than 1 second of arc can be displayed. The Electrolevel heads can be located at distances up to 300 feet from the detector. More detailed information about this tilt measuring device can be obtained from Tellurometer U.S.A. Division of Plessey Incorporated, 87 Marcus Boulevard, Hauppauge, New York 11787.

* b. Applied Geomechanics AGI 700. This tiltmeter is similar to the electrolevel, but measures tilt angles to a resolution of 0.02 seconds of arc. It is manufactured by Applied Geomechanics, Incorporated of Santa Cruz, California. The meter, along with a readout instrument, is shown in Figure 4-15. It is manufactured as both a single-axis and a dual-axis tiltmeter.

(1) Description. The AGI 700 surface mount tiltmeter detects tilt through the motion of a bubble in an electrolytic sensor similar to a spirit level. As the meter changes tilt angle, the sensor changes resistance. The resistance element is part of an internal bridge network, and the change in resistance affects the output voltage of the tiltmeter.

(2) The AGI 700 electronics are contained on three printed circuit boards in the meter. The Power Supply board contains the power supply regulating circuitry. The AGI-700 is externally powered by a ±12 VDC, 50 mA power supply. This board also contains circuitry to perform temperature *

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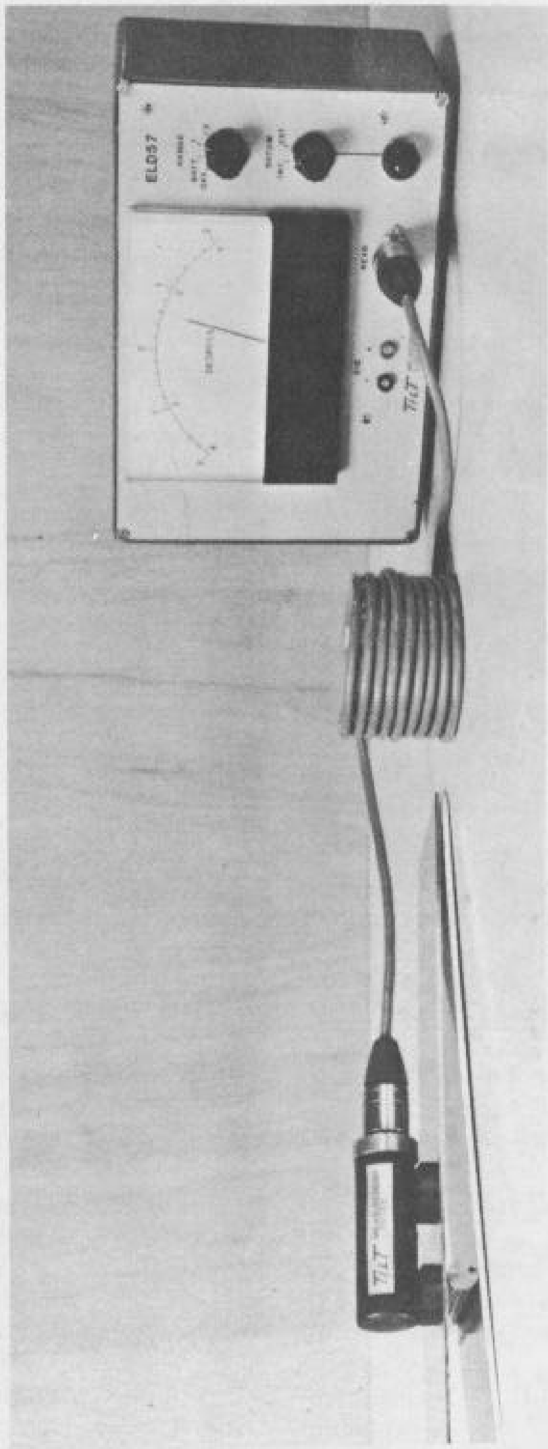

ELH/10

Figure 4-14. British Aircraft Corporation Electrolevel Unit
(Courtesy of Tilt Measurement Ltd.)

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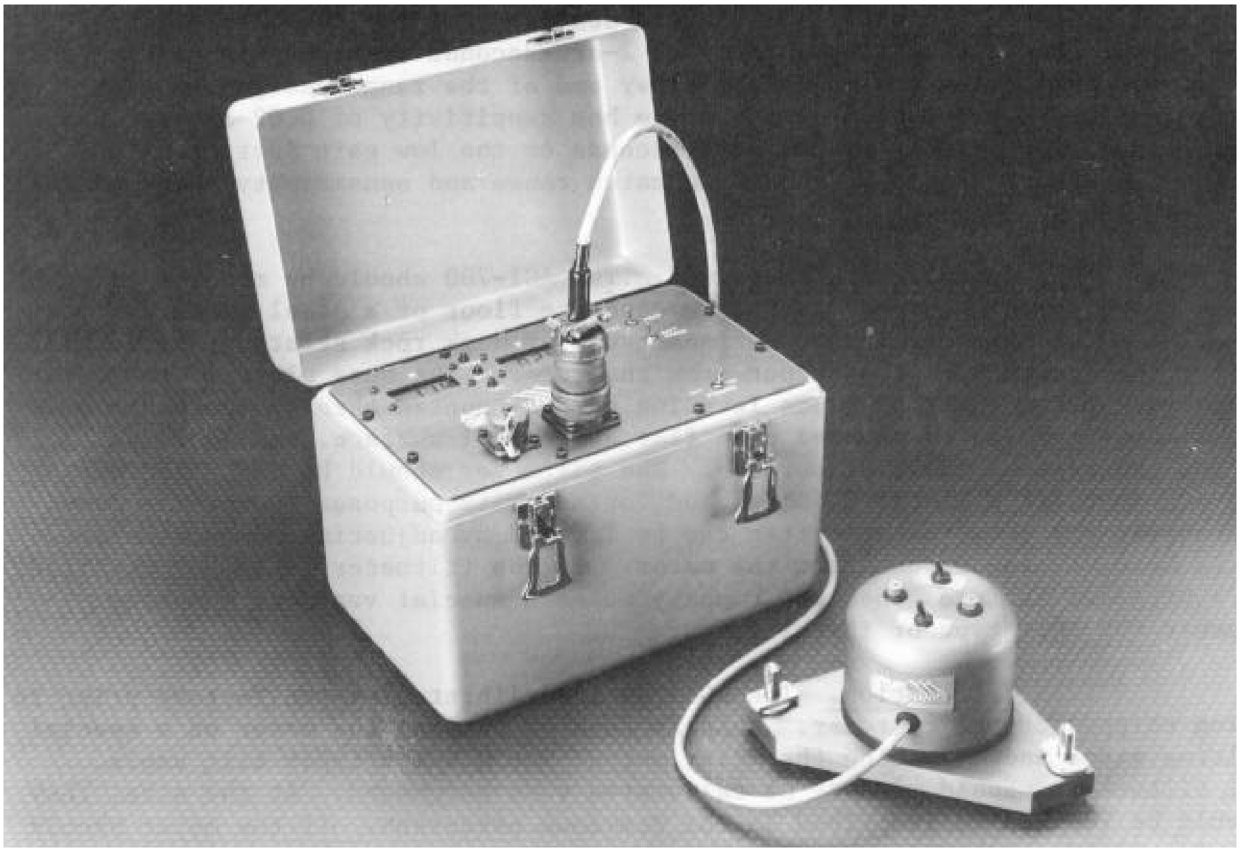


* Figure 4-15. Applied Geomechanics AGI 700 Surface Mount Tiltmeter with Read-Out Box

calibration and amplification, as well as provide clock circuitry. The dual amplifier circuit board contains the balance bridge, the amplifier, the rectifier, and output circuitry for both axes of tilt output. The third circuit board, the switchboard, contains gain and filter circuitry, switches to control these functions, and signal input/output circuitry.

(3) All circuitry as well as the sensors are housed in an anodized 6061-T6 aluminum dome and base. The dome is secured to the aluminum base and is gasketed at the intersection to prevent ingress of water and other foreign materials.

(4) Tilt Ranges. As conventionally manufactured by Applied Geomechanics, the AGI-700 can measure tilt angles in one of three ranges; ±60 degrees, ±5 degrees, and ±0.5 degrees. The company says they can custom manufacture sensors for other ranges. Within each range described above, the sensor can be adjusted to monitor one of two subranges by changing the position of a gain switch mounted on the dome of the meter. For example, a tiltmeter designed for the ±0.5-degree range can monitor tilting in the ±24-arc-minute range with the gain switch set to low, and monitors tilt angles of ±2.4 arc minutes with the gain switch set on high. *

* (5) Sensitivity. Tiltmeters designed for the ±60-degree range have output sensitivity (resolution) of 2-arc-seconds on high gain setting and 20-arc-seconds on low gain. On the other end of the range designs, a tiltmeter designed for the ±0.5-degree range has sensitivity of 0.02-arc-seconds on the high gain setting and 0.2-arc-seconds on the low gain setting. The particular sensor should be chosen to match range and sensitivity needs of the application.

(6) Installation Procedure. The AGI-700 should be mounted on a clean, hard, smooth surface such as a concrete floor or a steel girder. Mounting the tiltmeter on soft surfaces such as weak rock strata or soils will affect the accuracy of the output from the meter. The base plate of the meter comes with three Invar or brass leveling screws mounted through the plate. If the tiltmeter is to be mounted on a flat horizontal surface, the leveling screws can rest on the flat surface. The tiltmeter should be installed out of the way where it will not be disturbed for security purposes. Once the leveling screws are set, the tiltmeter can be leveled by adjusting the screws to get a zero voltage output from the meter. If the tiltmeter is to be installed on a vertical surface, then the company makes a special vertical mounting bracket for this type of installation.

(7) Calibration. The AGI-700 is calibrated at the factory prior to being shipped to the customer. This is done by putting the meter on a special tilting stage and adjusting the meter output for a known input tilt angle. All tiltmeters should already be calibrated when purchased. At the site, they should be leveled as described in the previous paragraph. If the meter should require field calibration, it can be removed from its measurement location and placed on a similar stage for calibration.

(8) Data Collection. The tiltmeter can be purchased with an Applied Geomechanics readout instrument, or it may be purchased separately and integrated into a data acquisition system. The AGI readout unit supplies the power to the tiltmeter, and provides a display for reading the tilt data. The readout unit has a rechargeable 12-V battery such that there is no need for access to an outlet when reading the meters. The AGI-700 plugs into the front of the readout unit (see Figure 4-15) and displays tilt for both x and y axes in terms of mV of output. The output mV are converted to angular degrees of tilt by applying a gain factor and a conversion factor supplied by the manufacturer.

c. Swiltometer. This instrument, manufactured by Structural Behavior Engineering Laboratories, Inc. of Phoenix, Arizona, is a subminiature servo system that mounts on a structure, or at any location within the structure, and is capable of measuring sway, tilt, settlement, and alignment of the structure at the point of attachment of the instrument. The Swiltometer is also capable of measuring dynamic motion due to its use of miniature accelerometers as sensing devices.

(1) Description. As shown in Figure 4-16, the Swiltometer is housed in a rugged casing which is securely bolted to the structure. The *

* casing is either aluminum or stainless steel depending upon the corrosive effects of the environment surrounding the meter. The base plate is an L-shaped plate welded to the casing. This plate allows the Swiltometer to be attached to either a vertical or horizontal surface. The sensing element is a D.C. servo accelerometer. There are three ranges of sensitivity, 0.1 G, 1 G, and 5G, with the 0.1-G range offering the highest degree of sensitivity. The Swiltometer requires a 15-volt battery for power and the output signal from the instrument is sent to a signal amplifier and then to the individual's choice of output display, voltmeter, millivolt strip chart recorder or oscilloscope. The Swiltometer can be used to measure tilt or used to gather acceleration data since the instrument can survive up to 100-G shock loads (momentarily). The instrument can measure tilt values as low as 0.0001 inches per foot which translates to approximately 2 seconds of arc. The tilt can be resolved into two components in two vertical planes, and as an accelerometer accelerations of as small as 0.001 G can be detected.

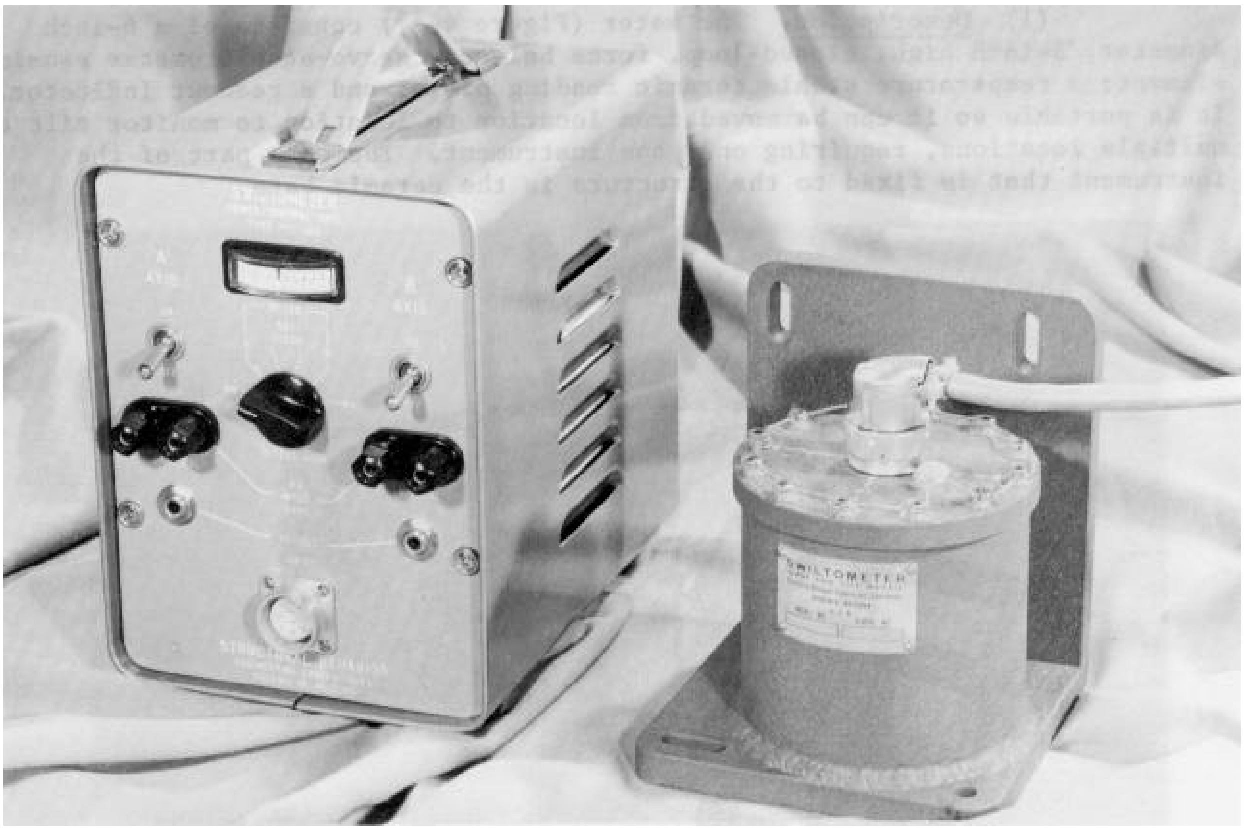


Figure 4-16. Swiltometer

(2) Installation Procedures. The Swiltometer is furnished with a leveling adapter which is a demountable turntable attachment to facilitate in checking the levelness of precision platforms and surface tables. The Swiltometer should be mounted on a flat metal platform which has been secured to the structure to be measured. The base or platform should be capable of being adjusted by means of a tribrach assembly in order to insure levelness at installation. The Swiltometer can be used to measure tilt at more than one location in a structure. For instance, if the tilt through a structure from *

*crest to foundation is desired, the instrument can be moved from one base plate to the next with readings being made and recorded at each location.

(3) Data Collection. In order to make static tilt measurements with the Swiltometer, the instrument must be connected to a power source/ control unit. This unit is also shown in Figure 4-16. A typical data plot would either be a graph of voltage (tilt) versus time in the case of an instrument monitoring one tilt location over a length of time, or voltage (tilt) versus location in a structure when the Swiltometer is moved through a structure to give a picture of tilt with respect to elevation.

d. Portable Horizontal-Vertical Tiltmeter. Slope Indicator Co. makes a surface-mounted tiltmeter that is portable end can measure tilt in both the vertical and horizontal planes.

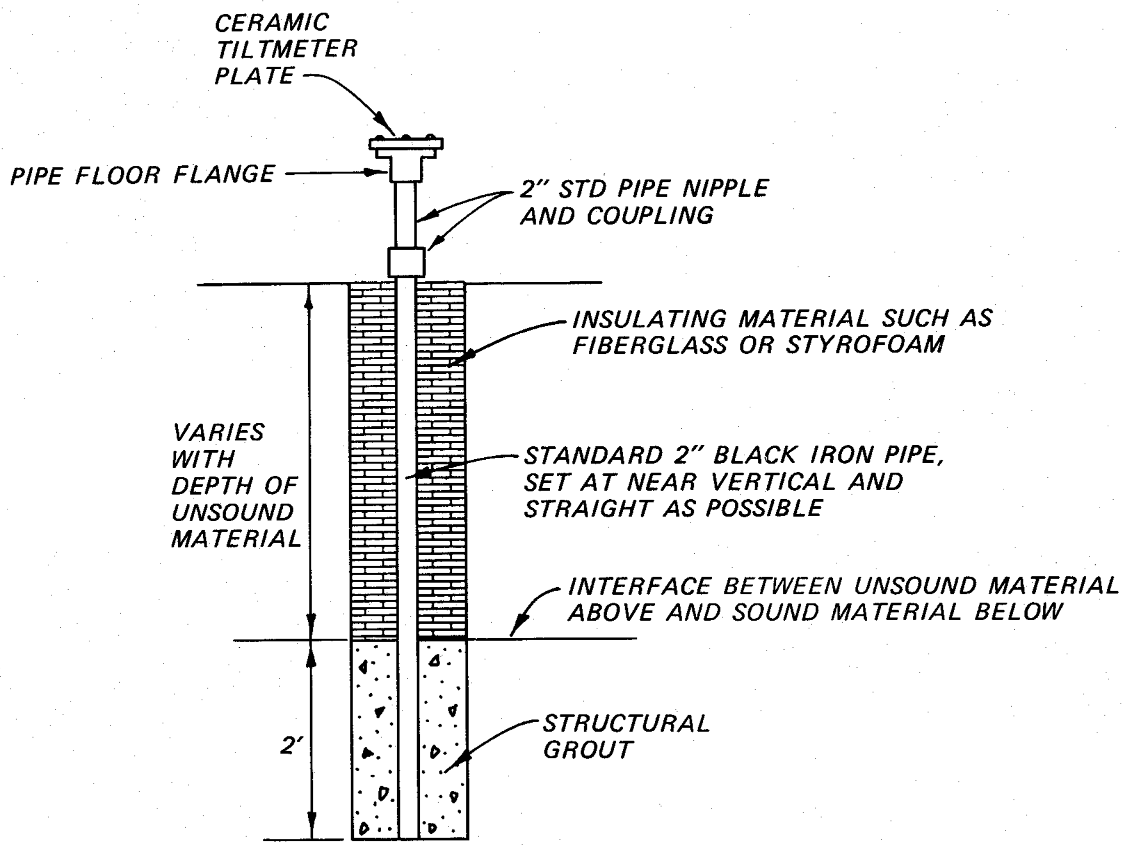
(1) Description. The meter (Figure 4-17) consists of a 6-inch diameter, 3-inch high, closed-loop, force balanced servo-accelerometer sensing element; a temperature stable ceramic reading plate; and a readout indicator. It is portable so it can be moved from location to location to monitor tilt at multiple locations, requiring only one instrument. The only part of the instrument that is fixed to the structure is the ceramic base.

Figure 4-17. Portable Horizontal-Vertical Tiltmeter Sensor in Reading Position on Ceramic Tilt Plate

* (2) Installation Procedures. The ceramic base plate is the portion of the instrument which is installed. It is bonded to the structure by means of grout or epoxy. Standard surface preparation procedures for epoxy-bonding should be followed in this matter. Every effort should be made to get the ceramic plate bonded in the horizontal plane or the vertical plane since any deviation will reduce the range through which the instrument will effectively operate. If the system is to monitor tilt in a structure where the surface material is not sound enough to act as a base for attachment of the meter, then the following procedure should be followed. The instrument will be mounted to a base plate assembly that is anchored into the structure a few feet below the surface of the structure. A borehole approximately 8 inches in diameter should be drilled down into sound material. The depth of penetration of the borehole through the sound material should be at least 2 feet. Blasting is not recommended since this could damage the sound material. A steel pipe 4 to 6 inches in diameter and long enough to reach from the bottom of the borehole to the surface of the structure should be inserted into the center of the borehole, and structural grout should be placed around the pipe up to the top of the sound material (Figure 4-18). When this has hardened, the remainder of the hole should be backfilled with a soft insulating material such as fiberglass or Styrofoam beads. This will insulate the exposed pipe shaft and prevent any movement of the base of the instrument due to temperature changes. It will also insure the isolation of the base of the instrument should the unsound upper layer of material have a tendency to move independently of the lower layer.

(3) Method of Operation. The portable tiltmeter utilizes a closed-loop, force-balanced servo-accelerometer similar to the Digitilt inclinometer (paragraph 4-10a.). It senses changes in tilt in one plane perpendicular to the surface of the ceramic plate. To operate, the sensor is lined up on three of the pegs in the plate and an angle is read on the four-digit indicator display. **The display reads 2 sine Θ over the standard operating range of ±30 degrees where Θ is the inclination from the vertical, thus** allowing angular deformations of 10 seconds to be monitored. This is equivalent to a displacement of 200 pinches over the 4-inch length between pegs of the ceramic plate.

(4) Calibration and Reading. A method of measuring the accuracy of the portable tiltmeter should be obtained. It should have a sensor that allows for checking of the tilt angles throughout the range of the tiltmeter from horizontal measurement through maximum angle of tilt with at least one intermediate measurement. The accuracy of the calibration device should be at least as accurate as the tiltmeter. The portable tiltmeter units should be calibrated both before and after each day's use. This will minimize the occurrence of instrument errors. At each ceramic plate, readings should be taken by wiping the plate with a clean dry cloth to make sure there is no debris on the plate and then placing the instrument on three of the four points on the plate and reading the output voltmeter. This procedure should be repeated until consistent readings are obtained. The instrument should then be rotated 180 degrees and the above procedure repeated. Pairs of readings taken 180 degrees apart are averaged to correct for face error. *



* Figure 4-18. Drilled-in Installation of Tiltmeter

Additionally, sets of readings similar to the above should be made with the instrument at 90 degrees to the original orientation to record the transverse tilt as well as the axial tilt of the structure. Typical reporting of results are by graph as shown in Figure 4-19.

e. Autocollimating Tilt Measurement Systems. A method of measuring tilt of a structure using an automatic level equipped with an autocollimating eyepiece and an optical vernier has been devised recently at the U.S. Army Engineer Topographic Laboratories. This system can measure both short- and long-term tilt of a structure and has the accuracy of about 2 seconds of arc over a range of ±7.5 minutes of arc.

(1) Description. The system, as shown in Figure 4-20, consists of a Zeiss Ni 2 Automatic Level, an autocollimating eyepiece, an optical vernier, and a calibration mirror. Long-term measurements of tilt are made of permanently mounted structure mirrors. These mirrors are attached to each vertical surface where measurement of tilt is required. As the vertical surface tilts, the mirror follows the movement and the system is designed to detect these small deflections. For short-term measurements, such as those encountered *

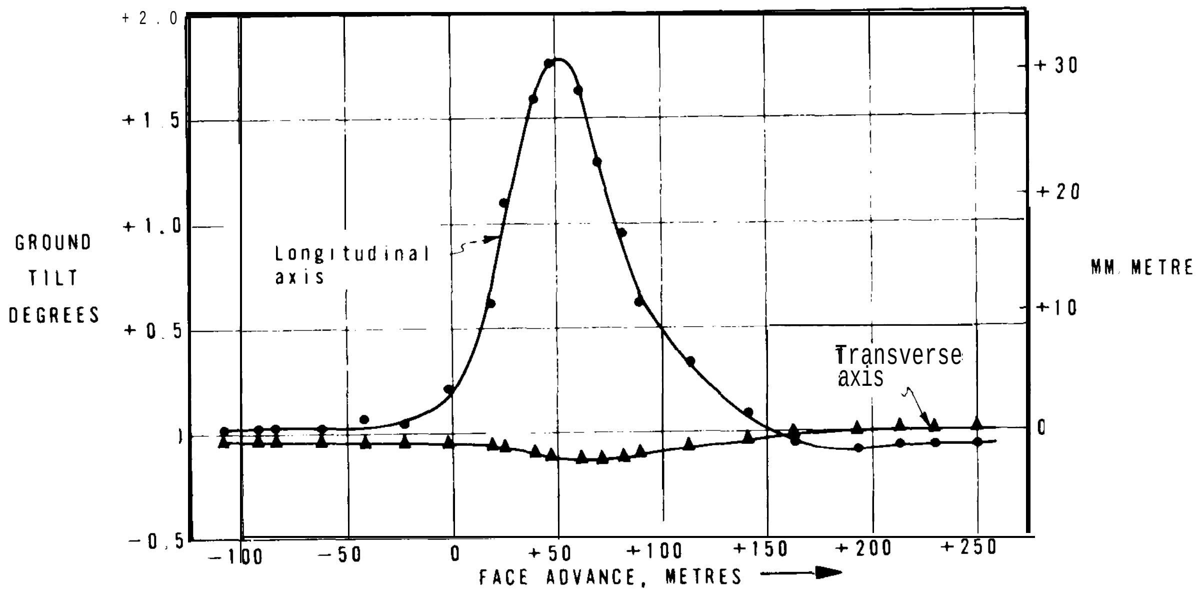


Figure 4-19. Typical Graph of Horizontal-Vertical Tiltmeter Data

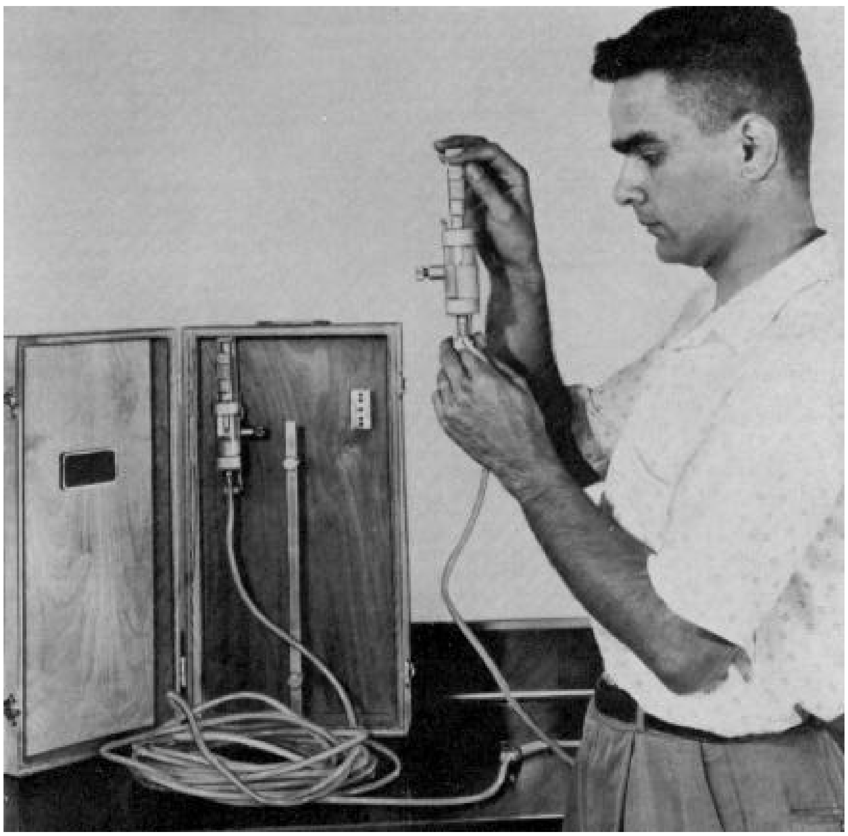


Figure 4-20. Autocollimating Tilt Measurement System

*during the filling-emptying cycle in a lock, a tripod mounted mirror may be used.

(a) Automatic Level. There are several competing automatic levels with comparable qualities. However, the Zeiss Ni 2 automatic level is the only automatic level known to be suitable because it is the only one which may be fitted with a standard autocollimating eyepiece and has a reticle graduated over a range of several minutes of arc.

(b) Autocollimating Eyepiece. The autocollimating eyepiece consists of a small lamp, half-silvered diagonal mirror, a reticle for reading angles, and an eyepiece for viewing the reading reticle. The use of the autocollimating eyepiece will turn the automatic level into an autocollimator which is a widely used device for measuring small angles.

(c) Optical Vernier. The optical vernier consists of essentially an optical wedge mounted within a rotating stage. The optical vernier may be used to deviate the line of sight by a known amount. In use, the wedge is rotated until the cross hair image is brought into coincidence with one of the reticle graduations. The rotation of the wedge needed to accomplish this is an accurate measure of the difference in seconds between the image and the reticle line.

(d) Calibration Mirror. Because of the errors in the automatic level compensator and in the positioning of the autocollimator reticle, it is necessary to calibrate the system before use so that all measurements, even those taken years apart, will be related to a common base, i.e., the direction of the vertical or gravity vector. The calibration of the system is performed by using a calibration mirror which consists of a two-sided mirror mounted to a tribrach in an approximately vertical position and a reading of tilt is made of one face with the instrument. Without moving the calibration mirror, the instrument is then used to make a reading of the other face. The mean of the two readings is the error of the system and should be used to correct the readings of the structure mirrors.

(e) Structure Mirror. The mirror assembly consists of a high quality surface mirror and an adjustable mirror mount. The mirror is round, approximately 2 inches in diameter and l/2 inch in thickness. The purpose of the adjustable mount is to both hold the mirror rigidly in position and to provide a means for initially adjusting the mirror to a nearly vertical position.

(2) Installation Procedures. The structure mirrors are the only part of the system that must be installed. The mirror must be mounted in such a manner that it accurately follows the tilt of the structure. In addition, the mount must not distort the mirror so that an unclear image is seen in the autocollimator. Using l/4-inch-diameter stainless steel anchor bolts and stainless washers for mounting the mirror is recommended. The anchors bolts should have a sufficient length to provide at least l-1/2 inches of embedment *

*length. A steel metal cover box may be used to protect the mirror surface from damage and to protect the mirror assembly from accidental movement.

(3) Method of Operation. When the lamp of the autocollimating eyepiece is turned on, it illuminates the cross hair of the automatic level. The focus of the level is set for infinity and the objective lens of the level projects an image of the cross hair along a collimated beam against a structure mirror, the tilt of which is being measured. The structure mirror, which *is* usually placed within a few inches to a few feet from the instrument, reflects the cross hair image back into the level, where it comes to a focus in the plane of the original cross hair. An observer looking into the eyepiece will see both the cross hair and its image, with the displacement between the two being proportional to the degree of the tilt of the structure mirror. The observer will *also* see the measuring reticle graduated *in* increments of 10 arc seconds. Using this reticle and the displacement between the cross hair and its image, a quantitative measurement may be made of the tilt of the mirror with respect to the optical axis of the level. Detailed instruments for assembly of the instrument, calibration, and measurements of the tilt of the structure mirror can be obtained from U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA.

4-12. Terzaghi Water Level Meter.

a. General. The Terzaghi water level meter is used to measure differences in elevation of floors, footings, columns, walls, galleries in dams or any place where leveling could be used. *Most* frequent use of the water level is in measurement of differential settlements in structural foundations in buildings, power plants, dams, and similar structures. The measuring points *can* be permanently or semi-permanently installed in walls, columns, *or* piers for measurement against a permanent bench mark. Its principle of operation is the measurements of the water level in two cylinders that are connected by *a* flexible tube. The water level *may* be used to determine differences in elevation between two points to an accuracy of 0.005 inch within a range of 6 inches. The apparatus shown in Figure 4-21 consists of two plastic sight tubes each of which is connected with a variable height setting to *a* mounting frame. The cylinders may be positioned on the mounting frame at l/2-inch intervals over a range of 6 inches. The two sight heads are connected with plastic tubing and have *air* relief valves. Also, a tapered-point micrometer, graduated to 0.001 inch is mounted in each sight head. By setting the point of the micrometer at the water level in each cylinder and reading the micrometer and mount setting, the difference in elevation between fixed points on each cylinder assembly may be determined.

b. Operation. *To use the water* level, both cylinders and tubing *are* filled with water that is free from air bubbles. The two cylinders are placed into their frames such that the water level is within range of the point of the micrometers. The observations are taken simultaneously, and a minimum of two sets of readings should be taken. After making the first set of readings, the cylinder assemblies should be interchanged and a second set of readings

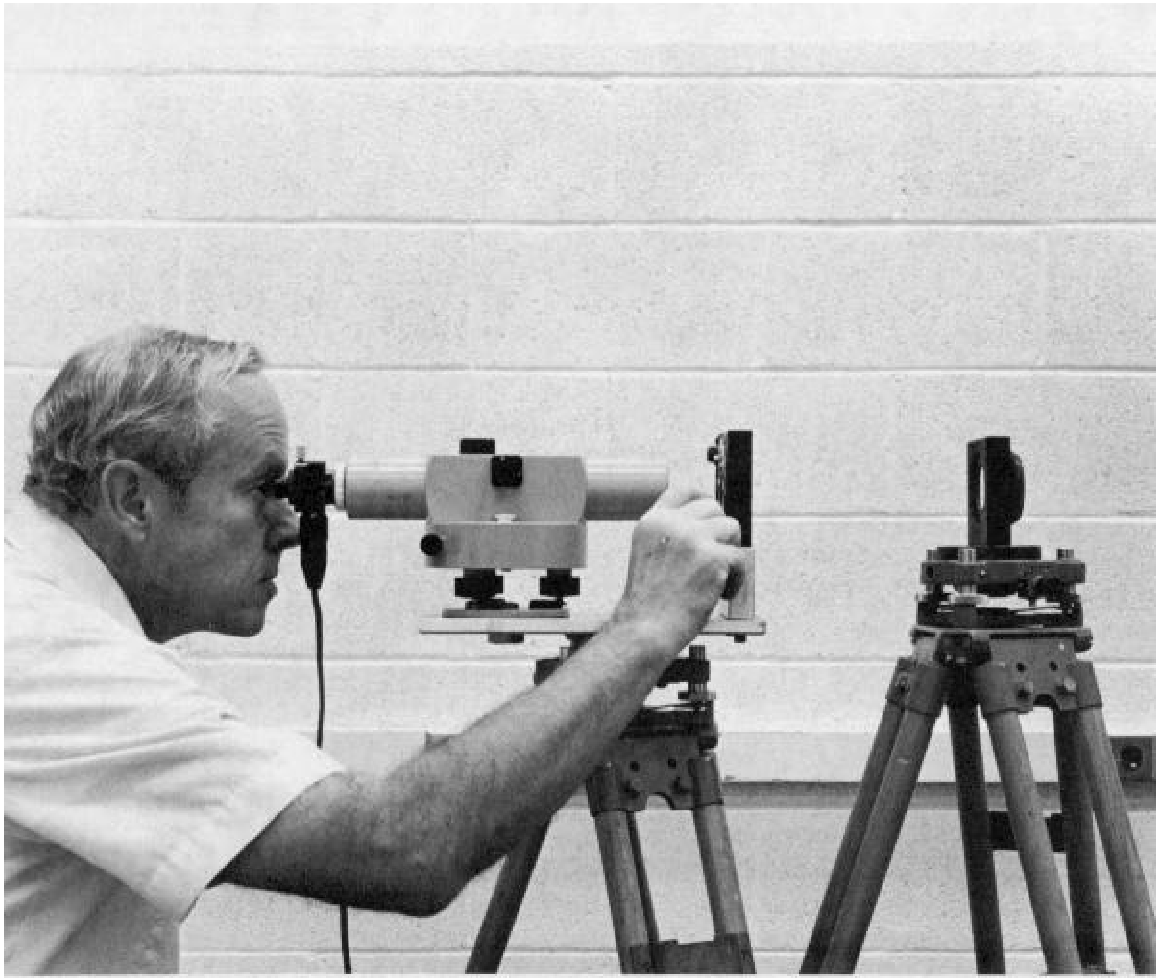


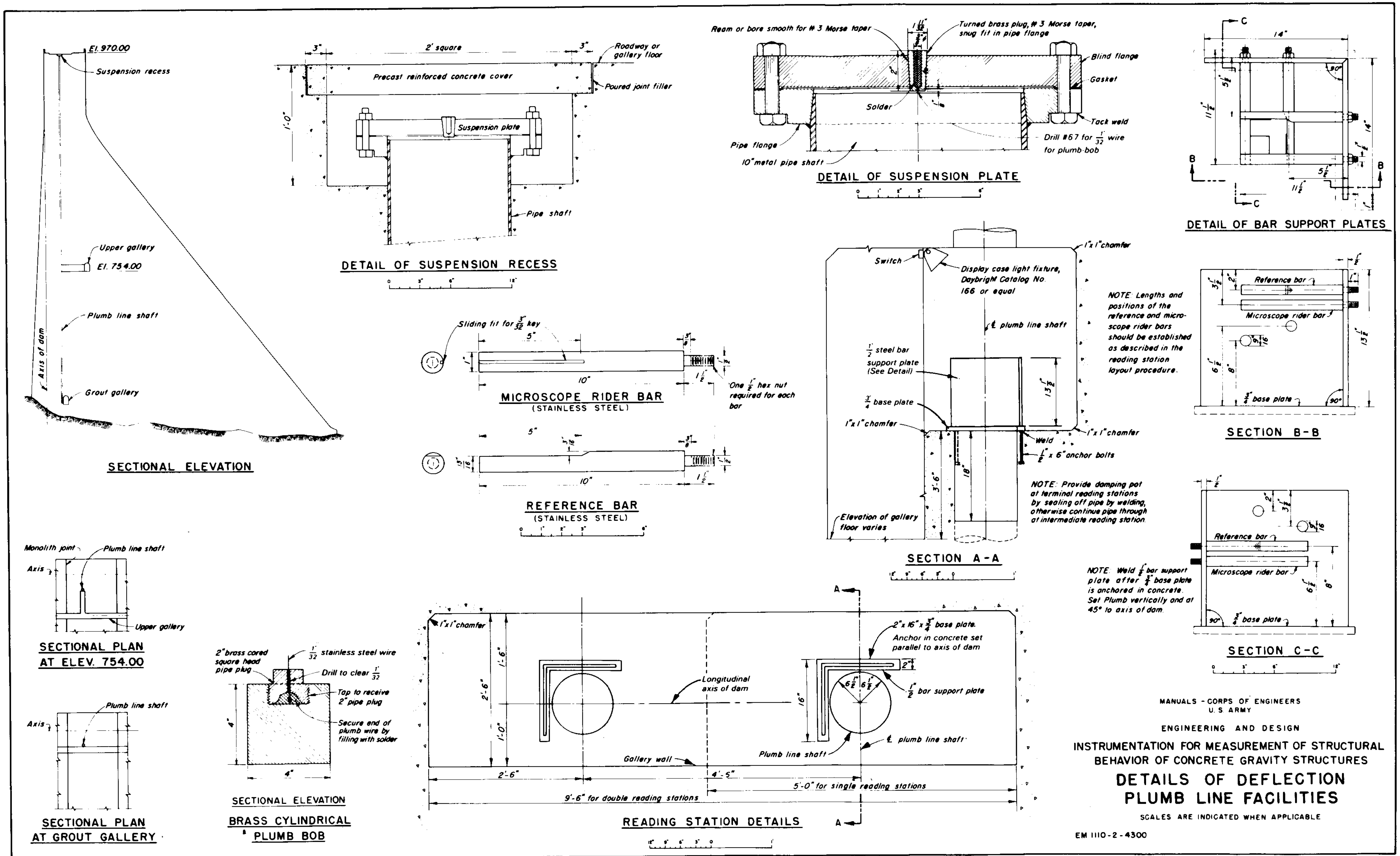
Figure 4-21. Terzaghi Water Level Gage (Courtesy of Soiltest Inc.)

taken. The difference in elevation between the two points should then be computed as the average of the difference of the two readings.

c. Reading the Gage. In making a measurement, the reading should be taken when the micrometer point just touches the water surface. To record a reading, count the number of holes above the base of the mounting frame to and including the hole where the head is attached. The lowest hole should be considered as zero. Multiply the number of holes by 1/2, and record this as inches. Read the micrometer setting, and add this value to the above. The micrometer is graduated to readings of 0.001 in. The numbers on the micrometer post represent tenths of inches. The sum of the mounting frame reading in inches and the micrometer reading represent the total reading and should be recorded. The difference between the recorded values for each cylinder represents the difference in elevation between the mounting points.

a. Precautions. The tube connecting the levels should not be exposed to variations in temperature throughout its length, since local changes in density of water will occur. For this reason it is necessary to isolate the tube from any hot water pipes, etc., and also to keep it out of direct sunlight. If it is necessary to use this instrument in sub-freezing temperatures, it has been found that a saturated salt solution can be used in place of water. Such a solution is well suited for this purpose since its coefficient of volume change is considerably smaller than that of other common antifreeze solutions.

e. Availability. This gage is not commercially available, but complete plans for construction of a gage can be obtained from either the Structures Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, or the Structures Branch, U.S. Army Corps of Engineers, Washington, DC.


El. 970.00
Suspension recess
Upper gallery
El. 754.00
Plumb line shaft
Axis of dam
Grout gallery
SECTIONAL ELEVATION
2' square
Roadway or gallery floor
Precast reinforced concrete cover
Poured joint filler
Suspension plate
Pipe shaft
DETAIL OF SUSPENSION RECESS
Ream or bore smooth for # 3 Morse taper
Turned brass plug, # 3 Morse taper, snug fit in pipe flange
Blind flange
Gasket
Solder
Tack weld
Pipe flange
Drill #67 for 1/32" wire for plumb bob
10" metal pipe shaft
DETAIL OF SUSPENSION PLATE
14"
DETAIL OF BAR SUPPORT PLATES
Sliding fit for 3/32" key
One 1/2" hex nut required for each bar
MICROSCOPE RIDER BAR
(STAINLESS STEEL)
REFERENCE BAR
(STAINLESS STEEL)
1" x 1" chamfer
Switch
Display case light fixture, Daybright Catalog No. 166 or equal
℄ plumb line shaft
1/2" steel bar support plate (See Detail)
3/4" base plate
Weld
1/2" x 6" anchor bolts
NOTE: Provide damping pot at terminal reading stations by sealing off pipe by welding, otherwise continue pipe through at intermediate reading station.
Elevation of gallery floor varies
SECTION A-A
NOTE: Lengths and positions of the reference and microscope rider bars should be established as described in the reading station layout procedure.
Reference bar
Microscope rider bar
SECTION B-B
NOTE: Weld 1/2" bar support plate after 3/4" base plate is anchored in concrete. Set Plumb vertically and at 45° to axis of dam.
SECTION C-C
Monolith joint
Axis
Upper gallery
SECTIONAL PLAN
AT ELEV. 754.00
SECTIONAL PLAN
AT GROUT GALLERY
2" brass cored square head pipe plug
1/32" stainless steel wire
Drill to clear 1/32"
Tap to receive 2" pipe plug
Secure end of plumb wire by filling with solder
SECTIONAL ELEVATION
BRASS CYLINDRICAL PLUMB BOB
2" x 16" x 3/4" base plate. Anchor in concrete set parallel to axis of dam
Longitudinal axis of dam
1/2" bar support plate
Gallery wall
Plumb line shaft
2'-6"
4'-5"
9'-6" for double reading stations
5'-0" for single reading stations
READING STATION DETAILS
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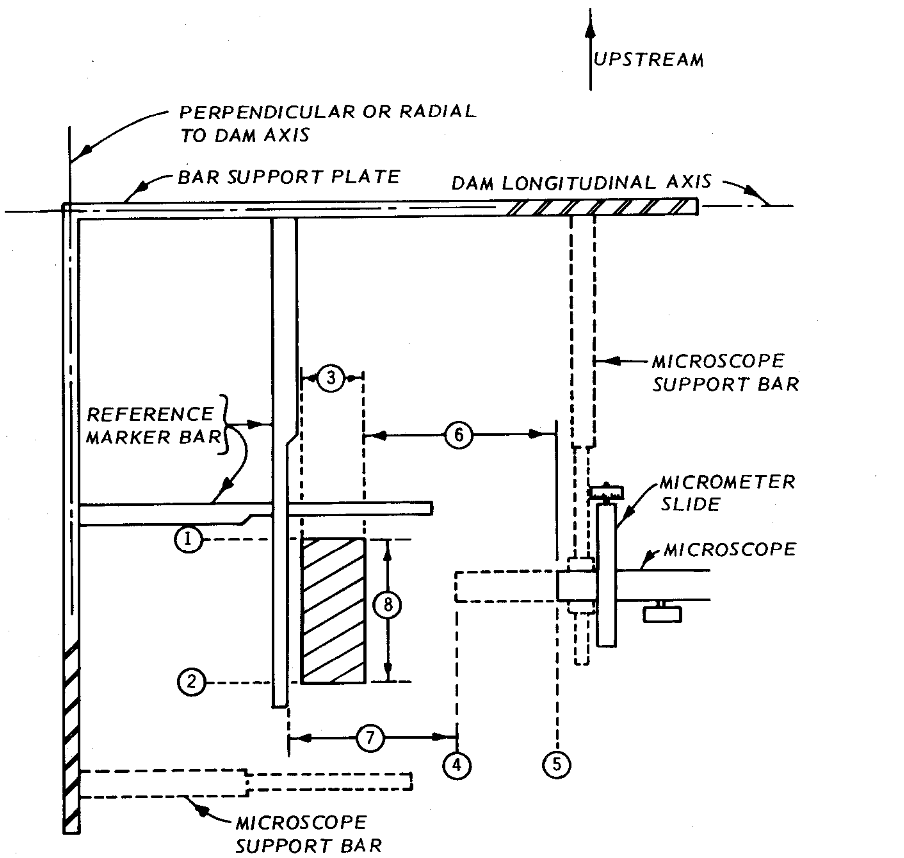
INSTRUMENTATION FOR MEASUREMENT OF STRUCTURAL BEHAVIOR OF CONCRETE GRAVITY STRUCTURES
DETAILS OF DEFLECTION PLUMB LINE FACILITIES
SCALES ARE INDICATED WHEN APPLICABLE
EM 1110-2-4300

PLATE 4-1



LEGEND

1. EXTREME LIMIT OF EXPECTED PLUMB LINE MOVEMENT UPSTREAM.
2. EXTREME LIMIT OF EXPECTED PLUMB LINE MOVEMENT DOWNSTREAM.
3. ALLOWANCE FOR TRANSVERSE MOVEMENT (APPROX 1/4 DISTANCE BETWEEN 1 AND 2).
4. MICROSCOPE DRAW TUBE EXTENDED.
5. MICROSCOPE DRAW TUBE RETRACTED.
6. MECHANICAL WORKING DISTANCE OF MICROSCOPE.
7. -DO-
8. RANGE OF MOVEMENT TO BE MEASURED BY MICROMETER SLIDE.

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DETAILED LAYOUT REQUIREMENTS OF PLUMB LINE READING STATION FACILITIES

EM 1110-2-4300

PLATE 4-2

______ PROJECT

FIELD READING SHEET-DEFLECTION MEASUREMENTS

MONOLITH ______ PLUMB LINE NO. ______ READING STA. ELEV. ______ DATE ______ TIME ______

WEATHER ______ MEAN DAILY TEMP. ______ POOL ELEV. ______ TW ELEV. ______

BAR	TRIAL	REFERENCE MARK			PLUMB LINE							DEFLECTION	
		FROM RIGHT	FROM LEFT	AVG.	RIGHT EDGE			LEFT EDGE			CENTER-LINE	IN.	POSI-TION
					FROM RIGHT	FROM LEFT	AVG.	FROM RIGHT	FROM LEFT	AVG.			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)

EXPLANATION:

IN COL. 1 SHOW REFERENCE BAR DESIGNATION.

IN COL. 2 SHOW OBSERVATION TRIAL NUMBER. A MINIMUM OF 3 TRIALS ARE USUALLY REQUIRED.

IN COLUMNS 3 AND 4 INSERT READINGS OF THE SLIDE MICROMETER WHEN THE MICROSCOPE IS CENTERED ON THE REFERENCE MARK FROM THE RIGHT AND LEFT, RESPECTIVELY.

IN COL. 5 INSERT THE AVERAGE OF COLS. 3 AND 4.

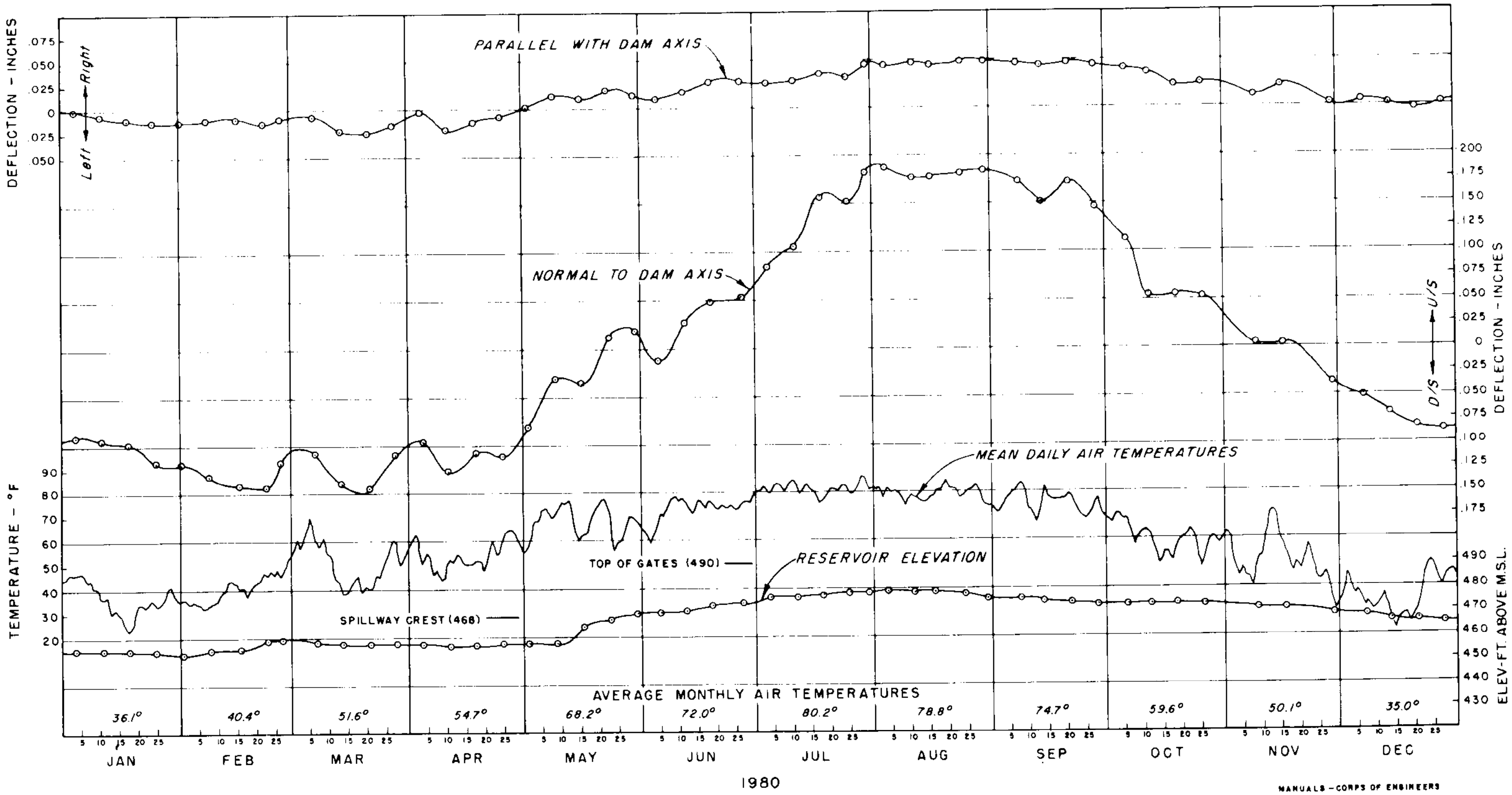
COLUMNS 6 AND 7, AND 9 AND 10, ARE SIMILAR TO COLS. 3 AND 4, BUT ARE RECORDED WHEN THE MICROSCOPE IS CENTERED ON THE PLUMB LINE.

COLUMNS 8 AND 11 ARE THE AVERAGES FROM COLS 6 AND 7,AND 9 AND 10.

IN COL. 12 RECORD THE MEAN OF THE VALUES IN COLS. 8 AND 11. THIS REPRESENTS THE POSITION OF THE CENTER OF THE PLUMB LINE WIRE.

IN COL. 13 INSERT THE NUMERICAL DIFFERENCE BETWEEN COLS. 5 AND 12, WITHOUT REGARD TO ALGEBRAIC SIGN.

IN COL 14 RECORD THE POSITION OF THE PLUMB LINE WIRE WITH RESPECT TO THE REFERENCE MARK, EITHER U/S OR D/S, OR R/A OR L/A WHEN READING PARALLEL TO DAM AXIS. THIS USUALLY CAN BE EASILY DETERMINED BY EYE WITHOUT THE USE OF THE MICROSCOPE.



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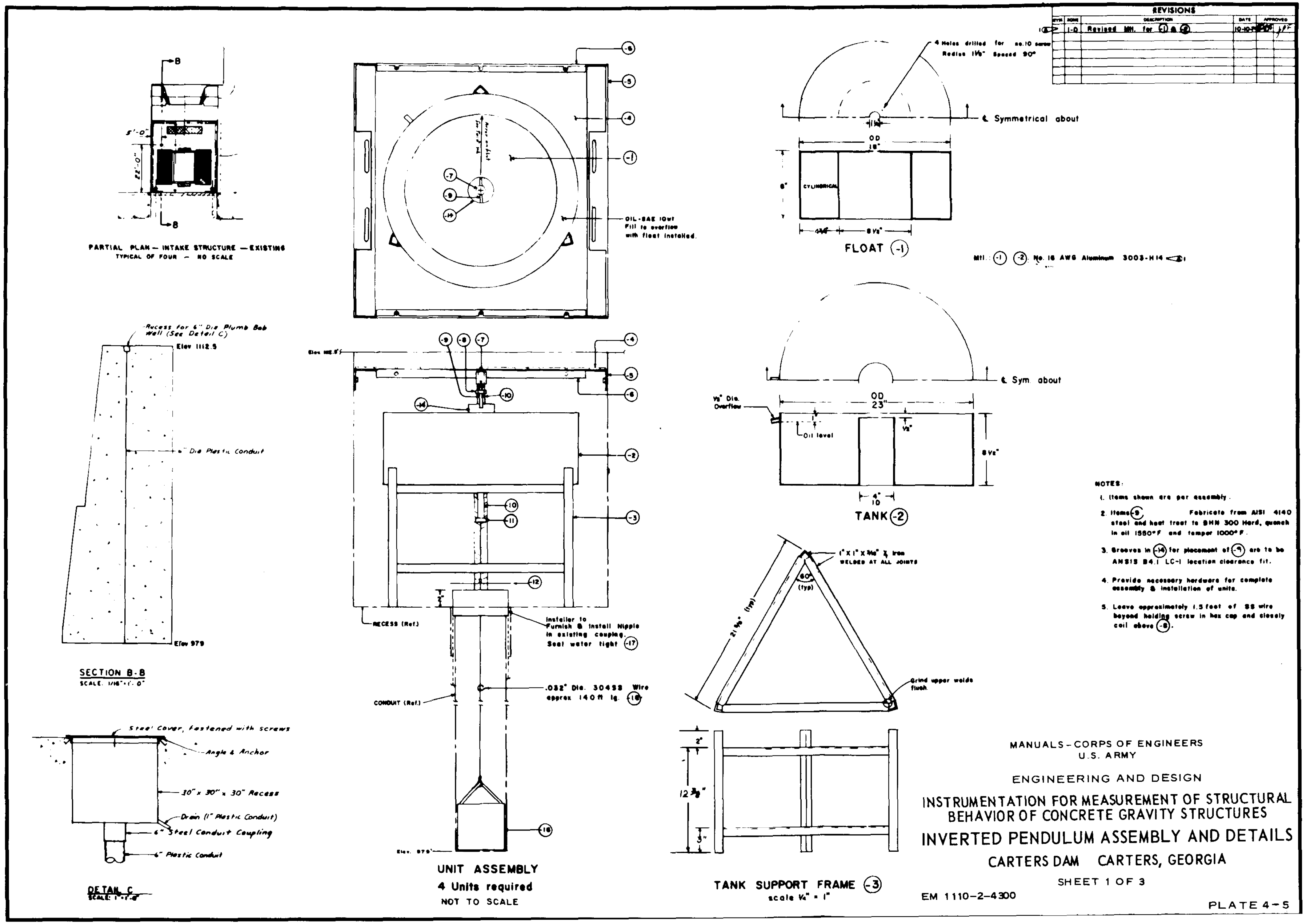
TYPICAL DEFLECTION HISTORY
(MONOLITH 13)

EM 1110-2-4300

PLATE 4-4

(Prepared by CE-WES)



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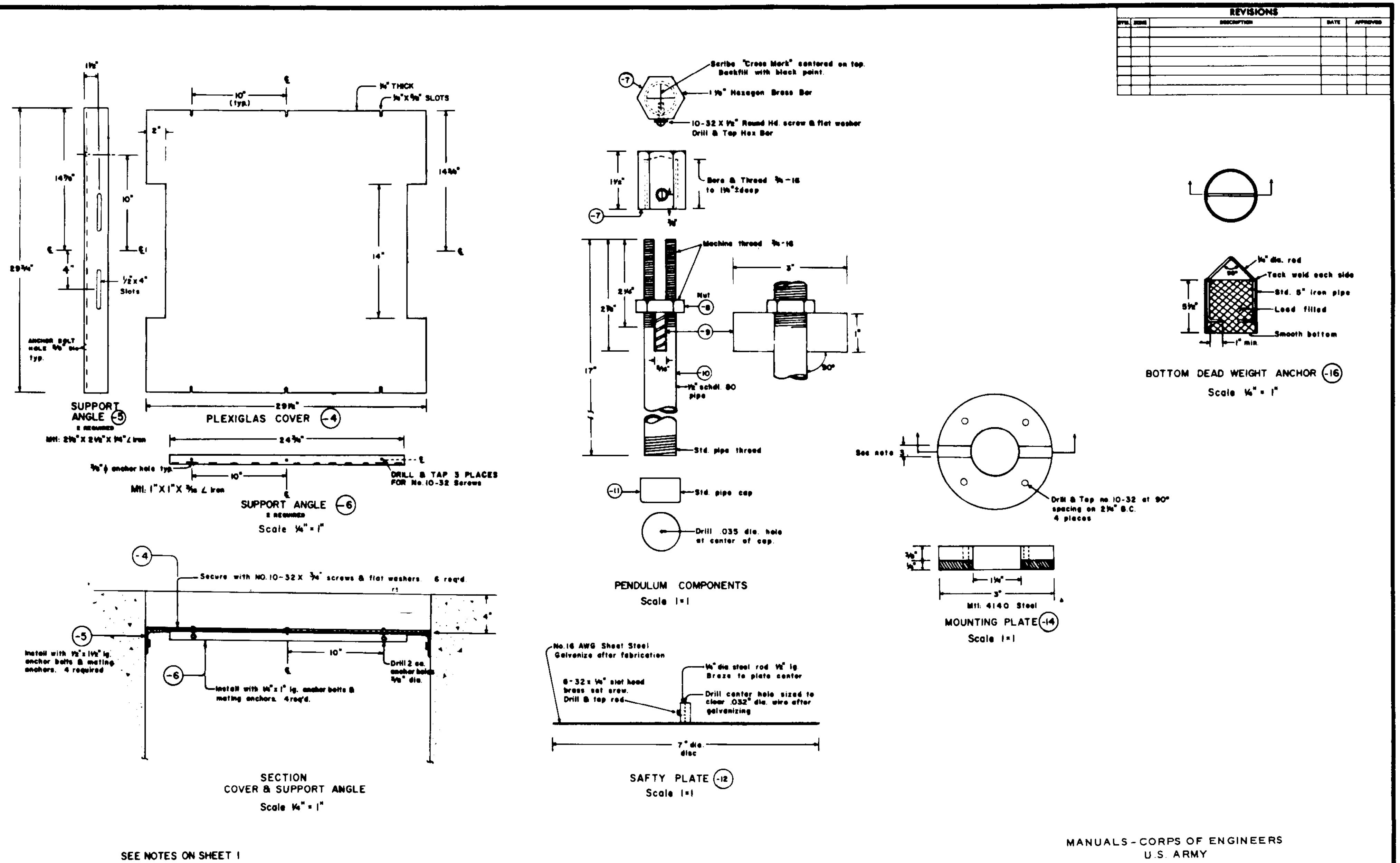
INSTRUMENTATION FOR MEASUREMENT OF STRUCTURAL BEHAVIOR OF CONCRETE GRAVITY STRUCTURES

INVERTED PENDULUM ASSEMBLY AND DETAILS

CARTERS DAM CARTERS, GEORGIA

SHEET 1 OF 3

EM 1110-2-4300



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INSTRUMENTATION FOR MEASUREMENT OF STRUCTURAL BEHAVIOR OF CONCRETE GRAVITY STRUCTURES

INVERTED PENDULUM ASSEMBLY AND DETAILS

CARTERS DAM CARTERS, GEORGIA

SHEET 2 OF 3

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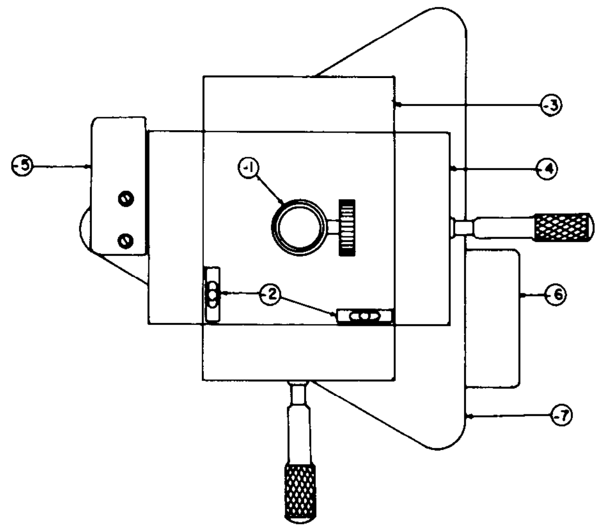
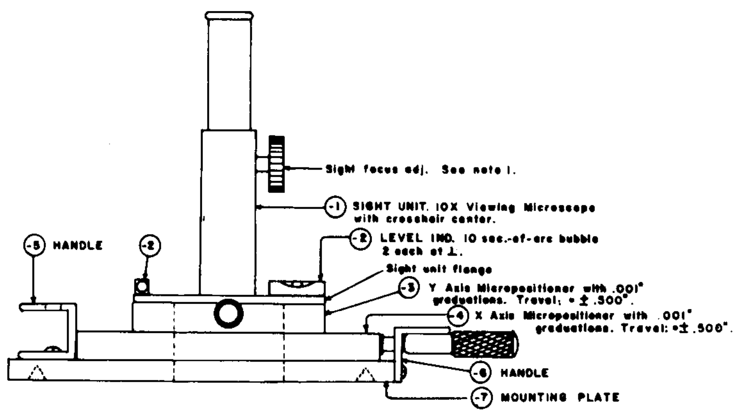
REVISIONS				
SYM	ZONE	DESCRIPTION	DATE	APPROVED



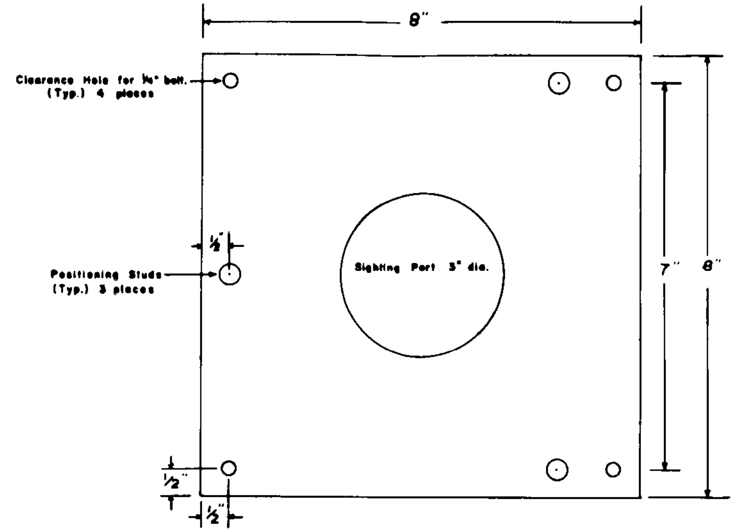
PLAN VIEW



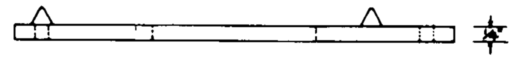
ELEVATION VIEW

SIGHT ASSEMBLY

1 Required



PLAN VIEW



ELEVATION VIEW

SUPPORT PLATE

Match Positioning Studs to -1 See note 2

4 Required

NOTES:

1. For required vertical coverage of Focus control see the specifications.

2. For required repeatable positioning on each respective Plate see the specifications.

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INSTRUMENTATION FOR MEASUREMENT OF STRUCTURAL BEHAVIOR OF CONCRETE GRAVITY STRUCTURES

OPTICAL PLUMB ASSEMBLY

CARTERS DAM CARTERS, GEORGIA

SHEET 3 OF 3

EM 1110-2-4300

PLATE 4-5